Analysis and Research on Building Foundation Selection in Soft Soil Area of Heqing, Yunnan Province

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Abstract: This paper analyzes the engineering geological conditions of a building site in Heqing, Yunnan Province, evaluates the seismic effect of the site and the uniformity of the foundation soil, and finally analyzes the foundation selection of the soft soil foundation site.

1 INTRODUCTION

With its unique geographical environment and geological conditions, Heqing area of Yunnan Province brings many challenges to the foundation selection of construction projects. Among them, the selection of building foundation in soft land area is particularly critical, which is directly related to the safety, stability and economy of buildings. The purpose of this study is to analyze the geological and hydrological conditions of the soft soil area of Heqing, Yunnan Province, and to discuss the selection scheme of building foundation suitable for this area by combining the practical engineering experience and the existing research results.

2 PROJECT OVERVIEW

The proposed site is located in Yunhe Town, Heqing County. Heqing County is located in the northwest of Yunnan Province, at the southern end of Hengduan Mountain Range in western Yunnan, east of Yunling Mountain Range and north end of Dali Bai Autonomous Prefecture. Its geographical coordinates are 100°01 '-100°29' east longitude and 25°57'-26°42' north latitude. Yunhe Town is located in the center of Heqing County, the terrain is high in the west and low in the east. It is 129 kilometers to the south from Dali and 42 kilometers to the north from Lijiang. The proposed site is close to Yunxin Road and North Ring Road, and the traffic is very convenient. The location of the proposed site is shown in Figure 1.

The proposed project consists of 11 buildings with 7 floors above ground and one underground floor. The basement is distributed in the whole site, and the basement storey is 4.7m.

Figure 1: Location of the proposed site.

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3 REGIONAL GEOLOGICAL CONDITIONS

3.1 Topography

The proposed site is located in Yunhe Town, Heqing County, lake accumulation of highland mountain intermittent basin west, east of Yunxin Road, south of the North ring road, south of Huashu Village. The site was originally cultivated land with flat and open terrain. The site is a quaternary lacustrine sedimentary landform.

3.2 Regional Structure and Neotectonic Movement

Regionally, the site is located in the sag area of Lijiang platform margin in Yanyuan Basin of Yangtze platform, southwest of Lijiang fold belt. Heqinging-xinmincun fault and Heqinging-Junying fault are the main active faults of the site and its adjacent areas. It can be seen that the structure of the site is complex, faults are developed and neotectonic activities are frequent. Heqing is an intermittent depression basin in the plateau mountains.

3.3 Neotectonic Movement and Earthquake

The neotectonic movement in the area where the proposed site is located mainly shows that the Diancang Mountain has risen strongly and the mountain has risen strongly since the Tertiary period; Along the main fault, there are more than ten Cenozoic faulted basins at different heights. Folds and fractures can be seen in the Pleistocene deposits.

The region is affected by the intermittent and different movement of the modern crust, which makes the ground stress complex, faults developed and earthquakes relatively frequent.

4 SITE ENGINEERING GEOLOGICAL CONDITIONS

4.1 Formation Lithology

The foundation soil of the site is composed of silty clay, silt and clay of quaternary lacustrine sedimentary origin, except the surface of the site is filled and cultivated soil, which is divided from top to bottom as follows:

① Layer, cultivated soil: brown gray, slightly wet - wet, plastic state, underconsolidation, high compressibility, mainly composed of silty clay with a few gravel particles and a large number of plant roots. The buried depth is 0.00-1.50m, the layer thickness is 0.40-0.60m, and the top elevation is between 2199.03-2201.68m.

② 1 layer, mixed fill: brown gray, brown, slightly wet, loose state, mainly composed of silty clay mixed gravel particles, underconsolidation, buried depth 0.00m, layer thickness 0.50 ~ 1.90m, the top elevation between 2200.53 ~ 2201.98m. The side of the distribution site near the North Ring Road is backfilled during the construction of the North Ring road. The backfilling period is greater than 3 years, and the backfill is not rolled by layers.

③ Layer, silty clay: brown, brown yellow, wet, plastic state mainly, local hard plastic state, medium compressibility, section rough or slightly shiny, no shaking reaction, medium dry strength, medium toughness, local even gravel. The buried depth is 0.40-2.10m, the layer thickness is 0.70-3.00 m, and the top elevation is between 2198.53-2201.08m. It's distributed throughout the field.

④ Layer, silt: gray, brown gray, wet, soft plastic - fluid plastic state, high compressibility. The section surface is slightly shiny, no shaking reaction, medium dry strength, poor toughness, a little organic matter and a small amount of shell residue inside. The buried depth is 1.20-4.90m, the layer thickness is 2.70-7.50m, and the top elevation is between 2196.18-2199.88m. It's distributed throughout the site.

⑤ Layer, clay: gray, brown gray, wet, soft plastic state, high compressibility. The section surface is slightly shiny, no shaking reaction, medium dry strength, medium toughness, and partial shell residue. The buried depth is 6.30-9.00m, and the top elevation is between 2191.00-2194.52m, which is distributed in the whole site.

⑥ Layer, clay: gray, blue-gray, wet, soft plastic state, local plastic state, high compressibility. Section is slightly shiny, medium dry strength, medium toughness, no shaking reaction. The buried depth is 19.90-21.20m, and the top elevation is between 2178.23-2180.78m.

Based on the comprehensive analysis of the indoor geotechnical test and in-situ test, and combined with the calculation of relevant norms, the physical and mechanical index parameters of each soil layer are obtained comprehensively (see Table 1 for details).

Table 1: Physical and mechanical parameters of each soil layer.

Floor number	Geotechnical designation	natural density ρ (g/cm³)	Quick shear		Set fast		Triaxial (CU)		Compression test mean		Double bridge static test standard value		Precast pile		Bearing capacity characteristic value
			Cq (kPa)	Φq (度)	Ccq (kPa)	Φcq (度)	Ccu (kPa)	Φcu (度)	Es_{1-2} (MPa)	Es_{2-3} (MPa)	q_c (Mpa)	Fs (Kpa)	Standard value of limit side resistance Q_{sik}(kPa)	Standard value of ultimate end resistance Q_{pk}(kPa)	f_{ak} (kPa)
①	Cultivated soil	1.75*	15*	4*						3.0*	0.5	22.9			
①1	Miscellaneous fill	1.70*	14*	5*						3.5*					
②	Silty clay	1.78	35.0	7.4	38.5	8.9			5.43	6.84	0.77	32.7	65		130
③	muck	1.51	16.6	4.6			16.3	4.8	1.78	2.35	0.51	13.6	15		40
④	clay	1.56	17.9	4.7	32.0	6.7			2.80	3.35	0.74	15.6	25	1000	85
⑤	clay	1.55	16.8	4.7	26.8	6.6			2.94	3.67	0.84	17.9	27	1100	95

Note: Values marked with * are experience values

4.2 Bad Geological Effects and Special Soil

(1) Bad geological effects

The proposed site is located on the west side of Heqing Basin with open and flat terrain. According to the on-site engineering geological survey, no adverse geological effects and geological disasters such as karst, collapse, debris flow and landslide have been found in and around the proposed site.

(2) Special soil

① Filling

The filling soil in the site is formed by backfilling during the construction of the North Ring Road and has a large distribution range. The filling soil is only distributed near the North Ring Road in the whole site. The composition of the filling soil is mainly composed of silty clay mixed gravel, partial mixed gravel and block stone, and the backfilling period is more than 3 years. The thickness of the layer is 0.50 ~ 1.90m, which is not suitable for use as the foundation bearing layer, and it is recommended to remove it when the foundation pit is excavated.

② cultivated soil

It is mainly composed of clay soil mixed plant roots and a few gravel particles, which is in a plastic state and underconsolidated. This part of cultivated soil has been soaked by farmland irrigation water all the year round, and its property is poor. The layer thickness is 0.40-0.60m. It is recommended to remove all cultivated soil during foundation pit excavation.

③ soft soil layer

In the site, the ③ layer of silt, ④ layer of clay and ⑤ layer of clay are in the soft-plastic and fluid-plastic state, with high compressibility, low bearing capacity, poor physical and mechanical properties, and large layer thickness. It should not be used as natural foundation. It is suggested that the foundation should be strengthened or the building structure should be strengthened in the project construction, and the influence of soft soil subsidence should be considered in the design.

4.3 Site Hydrogeological Conditions

The stable water level in the inland of the site ranges from 0.37 to 1.93m, the water level elevation ranges from 2198.10 to 2201.20m, and the height difference is 3.10m. According to the characteristics of foundation soil, ① cultivated soil and ①1 layer of mixed fill have certain permeability, and the other viscous soil layers are weak permeability. Groundwater mainly exists in the silty clay (② layer), silt (③ layer), clay (④ layer) and clay (⑤ layer) with the change of climate, but the amplitude is small. Groundwater is fed by atmospheric precipitation, surface water and Caohai seepage, and discharged by atmospheric evaporation and infiltration into Bonan River, and then deposited in Caohai. The exploration and construction period is in the rainy season, and the water level is greatly affected by the season. According to the hydrogeological data collected by our institute in

Table 2: Groundwater corrosivity evaluation table.

Corrosive medium	The content in water (mg/l)		Climate influencing factor		Osmotic factor		Corrosion grade of concrete structure by water	Corrosion grade of steel bar in concrete structure by water
	ZK1	Zk25	Environmental category	Corrosion grade	Penetration category	Corrosion grade		
Ca^{2+}	44.89	38.48	II	weak			weak	weak
Mg^{2+}	11.67	36.95						
$K^{+}+Na^{+}$	151.91	149.37						
SO_4^{2-}	40.38	28.13						
PH	7.00	7.01			**A**	weak		
侵蚀性 CO_2	4.40	8.80						
HCO_3^{-}（mol/l）	6.80	7.00						
Cl^{-}	14.18	21.27						
Comprehensive evaluation of corrosiveness level	weak		Groundwater has slight corrosiveness to concrete structures in Class II site environments and steel structures in reinforced concrete structures					

this area, 0.0-0.37m below the surface is the highest water level in this area in recent years, and the variation range of the highest groundwater level is within 1m. According to the site topography, hydrogeological conditions and the final leveling of the elevation, it is suggested that the anti-floating design water level should be 2201.50m, and anti-floating treatment measures should be carried out in accordance with relevant norms.

4.4 Analysis of Soil and Water Corrosion

According to the relevant provisions of the Code for Geotechnical Engineering Investigation (8th edition of 2009) (GB50021-2001, 2009), groundwater is slightly corrosive to concrete structures. It is slightly corrosive to reinforcement in concrete structure. Specific evaluation is shown in the table below in Table 2.

According to the corrosion analysis of soil samples taken from drilling, the PH values are 7.01 and 7.04 respectively, belonging to weakly alkaline soil, and the site environment type is Class II. According to the Code for Geotechnical Engineering Investigation (GB50021-2001) (2009 edition), it is comprehensively determined that the foundation soil of the site is slightly corrosive to the concrete in Class II site environment and the reinforced concrete and steel structure in the concrete (see Table 3 for details).

Table 3: Soil corrosivity evaluation table.

Corrosive medium	The content in the soil(mg/kg)		Climate influencing factor		Osmotic factor		Corrosion grade of soil to concrete structure	Corrosion grade of soil to reinforcement in concrete structure
			Environmental category	Corrosion grade	Penetration category	Corrosion grade		
	Zk2-6	Zk37-2	II	weak	A	weak	weak	weak
Ca^{2+}	19.24	17.64						
Mg^{2+}	4.86	17.50						
Soluble salt（%）	0.0216	0.0283						
SO_4^{2-}	29.15	26.80						
PH	7.01	7.04						
HCO_3^-	170.86	219.67						
Cl^-	21.27	28.36						
Electrical resistivity (Ω.m)	60.00	60.00						
Comprehensive evaluation of corrosion grade	The soil is slightly corrosive to the concrete structure and the reinforcement in the reinforced concrete structure.							

5 ENGINEERING GEOLOGICAL EVALUATION

5.1 Evaluation of Seismic Effect

1．seismic fortification standards

According to the 2016 edition of the national seismic fortification intensity Code for Seismic Design of Buildings (GB50011-2010), the seismic fortification intensity of Heqing County is 8 degrees, the design basic earthquake acceleration is 0.30g, and the design earthquake is divided into the third group. The characteristic period of the site is 0.65s. The seismic facilities shall meet the requirements of the local seismic fortification intensity.

2. Venue category

The proposed site is located in Yunhe Town, Heqing County. The site is generally Huxiang sedimentary landform of the whole quaternary system. The seismic fortification category of this project is standard fortification category (Class C). According to the wave velocity report of drilling holes ZK17 and ZK27 under the surface of the site at a depth of 0-20m, the equivalent shear wave velocity is 158m/s and 159m/s respectively, and the thickness of the covering layer of the site is greater than 50m. According to articles 4.1.3 and 4.1.6 of the Code for Seismic Design of Buildings (GB50011-2010) (2016 edition), the site soil type is determined to be medium soft soil and the construction site category is Class III.

soft soil earthquake subsidence and sand liquefaction

There is no distribution of saturated sand and silt with a thickness of more than 0.5m in the depth of 20.0m in the proposed site, and there is no problem of liquefaction of saturated sand.

According to Article 6.3.4 of the Code for Geotechnical Engineering Investigation in Soft Soil Areas (JGJ83-2011) (J1186-2011), the seismic fortification intensity of the proposed site is 8 degrees, there is silt in the site, the equivalent shear wave velocity is less than 140m/s, and the bearing capacity is less than 100Kpa. The earthquake

subsidence value of the building is estimated at 150mm.

4. Seismic section division of building site

The topography of the site is large, the maximum height difference of the site is greater than 5.0m, the terrain is relatively open, there is no bad geological phenomena such as collapse, landslide, debris flow in the drilling range, but there is soft soil in the foundation soil, according to the Code for Seismic Design of Buildings (GB50011-2010) (2016 edition) 4.1.1 division standard, the site is divided into adverse seismic areas.

5.2 Site Stability and Suitability Evaluation

The overall terrain of the site is basically flat, and the terrain and geomorphology are complete. There are no undesirable geological effects such as Holocene active faults, slippage and debris flow within the drilling range. There is weak soil layer in the site, which can be used as the construction land of the project after the reinforcement treatment of the foundation or strengthening of the building structure.

5.3 Evaluation of Foundation Soil

The foundation soil of the site is composed of silty clay, silt and clay of Quaternary Huxiang sedimentary origin, except the surface of the site is filled and cultivated soil, which is divided from top to bottom as follows:

① Layer, cultivated soil: brown gray, slightly wet - wet, plastic state, underconsolidation, high compressibility, mainly composed of silty clay with a few gravel particles and a large number of plant roots. The physical and mechanical properties of this layer are poor, so it is recommended to remove all the soil during construction.

② 1 layer, mixed fill soil: brown gray, brown, slightly wet, loose state, mainly composed of silty clay mixed gravel particles, underconsolidated, distributed in the site near the North ring road side, for the construction of the North ring road backfill, backfill more than 3 years, backfill has not been rolled by layers. The soil of this layer is only produced in a local section, the uniformity is poor, and it is recommended to remove all the soil.

③ Layer, silty clay: brown, brown yellow, wet, plastic state, local hard plastic, medium compressibility, section rough or slightly shiny, no shaking reaction, medium dry strength, medium toughness, local even gravel, the whole field are distributed. The soil of this layer has good physical and mechanical properties, but the layer thickness is uneven, and some parts have been cleared after the excavation of foundation pit, so it is not suitable for use as the foundation supporting layer of the proposed building.

④ Layer, silt: gray, brown gray, wet, soft plastic - fluid plastic state, high compressibility. The section surface is slightly shiny, no shaking reaction, medium dry strength, poor toughness, a little organic matter and a small amount of shell residue inside. The physical and mechanical properties of this layer of soil are poor, and it is strictly prohibited to use as a natural foundation.

⑤ Layer, clay: gray, brown gray, wet, soft plastic state, high compressibility. The section surface is slightly shiny, no shaking reaction, medium dry strength, medium toughness, and partial shell residue. The physical and mechanical properties of this layer are better than that of the third layer, and it can be used as the supporting layer of the pile end of the proposed construction.

⑥ Layer, clay: gray, blue-gray, wet, soft plastic state, local plastic state, high compressibility. Section is slightly shiny, medium dry strength, medium toughness, no shaking reaction. It can be used as the supporting layer of pile end or the underlying layer of the proposed construction.

5.4 Evaluation of Foundation Uniformity

There is little difference in the composition, thickness, spatial distribution and physical and mechanical properties of each soil layer of the foundation, but the foundation soil of the site is medium-high compressibility foundation, the complexity of the site foundation is second class, and the ratio of the maximum and minimum compressive modulus of the layer silt is greater than 1.3. According to the current "Geotechnical Investigation Standard for High-rise Building Concrete" (JGJ/T72-2017 Article 8.2), it is determined that the site is an uneven foundation.

6 TYPE SELECTION DESIGN OF FOUNDATION

According to the characteristics of the proposed building and the engineering geological conditions of the site, it is not appropriate to use natural foundation in this project, and it is recommended to use pile foundation or composite foundation + raft foundation. The bearing layer of pile foundation and composite foundation should choose ④ layers of clay and ⑤ layers of clay. The basic form is suggested as follows:

(1) Composite foundation + raft: The solution of cored stirred pile composite foundation + raft foundation can be adopted for the foundation form of Building 1-11, Building 1 and pure basement. The effective pile length is about 15.00m, pile diameter is 0.50m, and ④ layer clay is used as the pile end bearing layer. The bearing capacity characteristic value of single pile is estimated to be 280KN, the pile spacing is 1.5m, the rectangular pile layout is m=0.087. The bearing capacity characteristic value of composite foundation is estimated to be 140-160KPa. The foundation soil of the proposed site is mainly silty clay, silt and clay with normal consolidation, and its natural water content is higher than 30%. Silt and clay plasticity index is greater than 25, according to local engineering experience, the site can be used as a core mixing pile foundation treatment.

(2) Pile foundation: For this project, static pressure prefabricated pipe pile and prestressed concrete pipe pile (PC) can be used. The effective pile length is about 20.00m, outer diameter is 0.50m, wall thickness is 0.10m, concrete strength is C60, and ⑤ layer clay is used as the pile end bearing layer. The estimated bearing capacity limit value of a single pile is about 1000KN in Table 4 and Table 5.

Table 4: calculation results of ultimate bearing capacity of single core-mixed pile.

Soil layer numbering	Soil layer name	Deep mixing pile		
		Characteristic value of soil side resistance q_s(kpa)		Characteristic value of bearing capacity of pile end soil q_p(kpa)
		Core pile segment	Coreless pile section	
③	muck	8	8	
④	clay	13	13	85
Estimated hole number	Pile end bearing layer	Pile dimension d×L（m）	Core length	Standard value of vertical ultimate bearing capacity of single pile Q_{uk} (kN)
ZK2	④clay	0.5×15.0	15	283.90
ZK25	④clay	0.5×15.0	15	284.75

Table 5: Estimation results of standard value of vertical ultimate bearing capacity (Quk) of single pile.

unit	Pile shape	Hole number	Pile diameter(mm)	Pile length(m)	Ultimate bearing capacity of single pile（kN）	Supporting course
Building 1-11 and the next one	Hydrostatic prefabricated pipe pile	Zk2	Φ500	20	1060.40	⑤
		Zk25	Φ500	20	1060.00	⑤

Note: 1. The bearing capacity of single pile is estimated according to the table above, and the test pile shall prevail according to the code requirements;

7 CONCLUSIONS AND SUGGESTIONS

7.1 Conclusion

(1) The proposed site is located in Yunhe Town, Heqing County, with silty clay and clay layer of Quaternary Holocene lacustrine sedimentary origin in addition to the soil filling and tillage on the surface.
(2) The proposed site has complete topography, open and flat terrain, small elevation difference, no Holocene active faults, slippage, debris flow and other adverse geological effects in the site, there is soft soil in the site, divided into adverse seismic areas, there is soft soil in the site, and it can be used as the construction land of the project after the foundation reinforcement treatment or strengthening of building structure measures.
(3) The seismic fortification intensity of the site is 8 degrees, the design basic seismic acceleration is 0.30g, and the design earthquake group is the third group. The site soil type is medium soft soil, the construction site category is Class III, and the site is an unfavorable seismic area.
(4) The seismogenic fault zones F166, F167 and F168 pass through about 4.50Km, 3.00Km and 2.30Km away from the proposed site.
(5) There is little difference in the composition, thickness, spatial distribution and physical and mechanical properties of each soil layer of the foundation, but the foundation soil of the site is medium-high compressibility foundation, and the complexity of the site foundation is second class. According to the uniformity evaluation standard of the current Geotechnical Investigation Standard for High-rise Building Concrete (JGJ/T72-2017), the foundation of the site is an uneven foundation.
(6) According to the soil analysis results, it is determined that the foundation soil of the site is slightly corrosive to the concrete in the Class II site environment, the reinforced concrete structure in the concrete and the steel structure.

7.2 Suggestions

(1) The upper part of the ground water in the site is pore diving, and the main aquifer is silty clay and clay layer. According to the water quality analysis results of the two groups of water samples taken in the site, the ground water is slightly corrosive to the concrete and the reinforced concrete structure in the concrete environment of the class II site. It is suggested that the design water level of anti-floating should be 2201.50m, and anti-floating measures should be carried out according to relevant specifications.
(2) The foundation type is suggested to adopt the foundation form of pile foundation or core-mixed pile composite foundation + raft. The construction of core-mixed pile or pile foundation should pay attention to the protection of the soil at the bottom of the pit before and after excavation to avoid disturbance as far as possible.
(3) The foundation pit support can be carried out in the form of moderate slope slope + steel sheet pile or double drainage soil mixing pile according to the actual situation. When the foundation pit is excavated, the water inflow of the foundation pit is large, and there should be better water separation and precipitation measures.
(4) The foundation pit of the proposed project is mostly located in the soft soil layer, and near the building, the foundation pit project is a dangerous project, the construction unit, the design unit, the construction unit, the supervision unit should strictly implement the relevant provisions of the "Safety Management Regulations of dangerous sub-projects" (2011, Ministry of Housing and Construction Order No. 37) during the design and construction process of the foundation pit.
(5) Because there is a thick layer of soft soil in the site, it is suggested that the uniformity and integrity of the building structure should be strengthened in the design to avoid uneven settlement.
(6) In the foundation construction process, the foundation soil should be avoided as far as possible by water immersion or exposure, and the construction should ensure the drying of the foundation pit, which is conducive to the construction. If abnormal phenomenon is found, please inform the design and investigation personnel to conduct on-site inspection of the tank, and study and solve the possible problems.
(7) After the foundation construction is completed, settlement observation points should be buried in time for settlement observation.

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