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Research on strengthening design of deep foundation pit of high-rise building-Taking stability calculation of deep foundation pit of a high-rise building in Zhanyi, Qujing City, Yunnan Province as an example

Yanfeng ZHAO[a] Shaohong PAN [a] Yanan SUN[b]
[a]Yunnan Land and Resources Vocational College,Yangzonghai Distrcit, Kunming, Yunnan Province,China1.
[b]Southwest Nonferrous Kunming Survey and Design (Institute) Co., LTD2
Email:873223692@qq.com

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1. Introduction

- With the emergence of high-rise buildings in cities, large numbers of deep foundation pit engineering has emerged.

- Although foundation pit project is a temporary project, due to various adverse factors in the construction process of foundation pit, surrounding foundation settlement, surrounding groundwater level drop, ground deformation, pavement cracking around deep foundation pit, warping, slope instability and other adverse effects affect the stability of foundation pit and the safety of surrounding buildings

- Based on the problems in the construction of deep foundation pit of a high-rise building in Zhanyi, Qujing City, Yunnan Province, this paper determines the stability of different positions of foundation pit through testing, identification and review, and proposes reinforcement schemes for unstable places to provide reference for similar foundation pit reinforcement projects.

2. Project Overview

- <u>2.1 Project profile</u>

  - The engineering data quoted in this paper are from Southwest Nonferrous Kunming Survey and Design (Institute) Co., LTD.
  - The proposed project consists of two 20-story high-rise buildings and a 4-story commercial podium building.
  - The layout of foundation pit is shown in Figure 1.

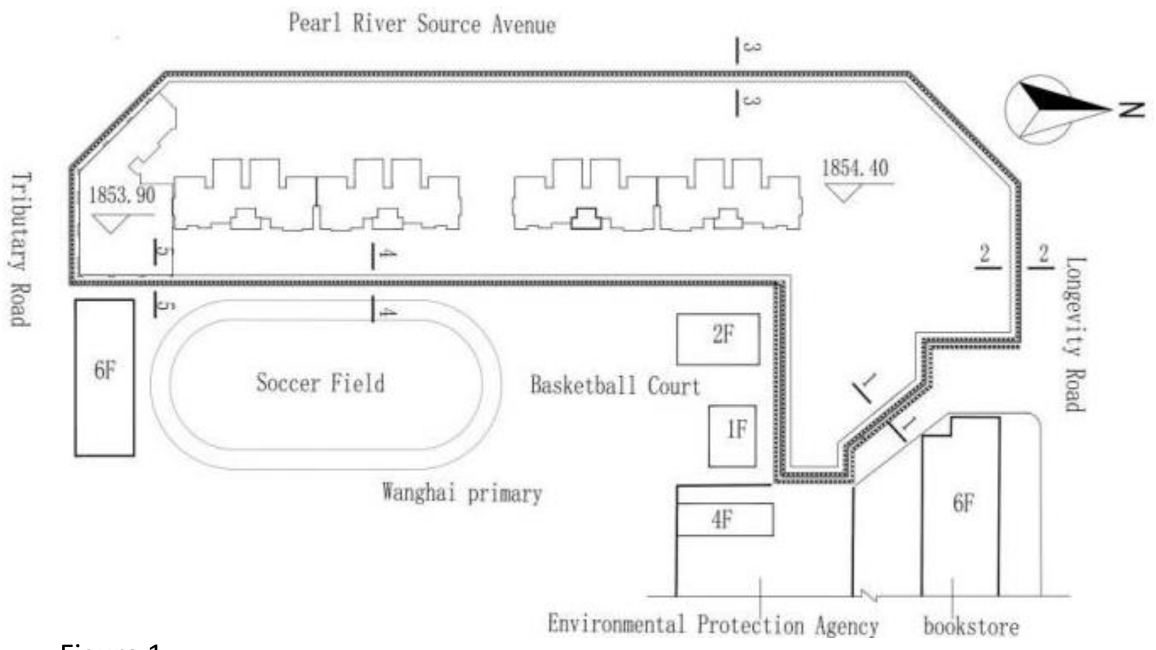


Figure 1

2. Project Overview

- <u>2.2 Site engineering geological condition</u>
  - the geotechnical layer of the site is composed of quaternary artificial fill (Q4ml) and cultivated soil (Q4pd), quaternary slope diluvium (Q4dl+pl), quaternary alluvial lake deposit (Q4al+l) and quaternary alluvium and diluvium (Q4al+pl).The depth soil layer parameters affected by foundation pit excavation and support are set to about -30.0m

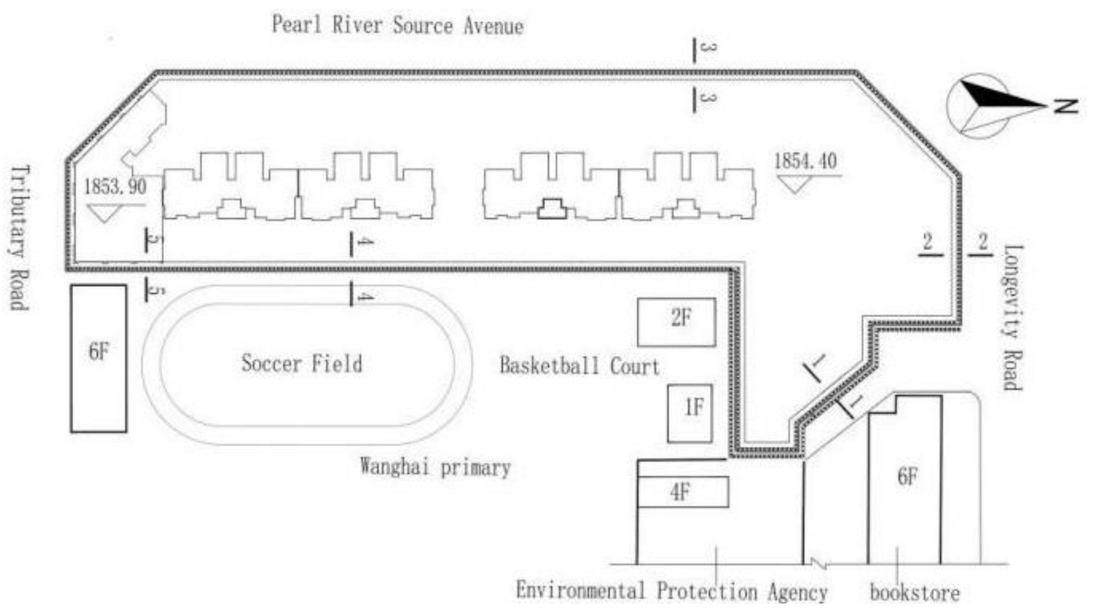
Soil layer numbering	Severe γ(KN / m³)	Shear strength		Calculated value		Characteristic value of bearing capacity of foundation Fak (Kpa)	Standard value of ultimate bond strength of anchor cable q_{sik} (Kpa)
		Cohesive force Ck (KPa)	Angle of internal friction Φk(°)	Cohesive force Ck (KPa)	Angle of internal frictionΦ(°)		
①Miscellaneous fill	18.6	18.32	6.62	18.32	6.62	50	30
②Silty clay	19.0	27.13	11.16	27.13	11.16	160	62
③$_1$Silty clay	19.1	26.17	10.3	26.17	10.3	140	58
③$_2$Silty clay	18.3	16.6	5.24	16.6	5.24	100	45
③$_3$Silty sand	19.5	0.0	21.0	5	24	190	95

Table 1

2. Project Overview

- <u>2.3 Site hydrological condition</u>
  - 2.3.1 surface water
    - There is no surface water and water system in and around the site.
  - 2.3.2 underground water
    - The stable groundwater level on the east side of the foundation pit is 2.10-2.50m below the current ground, and the buried depth of the groundwater level measured in the original detailed investigation is 0.20-2.00m, and the difference in the stable water level elevation between the two is not much.

- <u>2.4 Surrounding environment condition</u>



3. Reasons for foundation pit reinforcement

- Foundation pit construction has been carried out according to the original design drawings, supporting piles, crown beams, the first row of anchor cables have been completed.

Figure 3: Northward

Figure 5: Westward

Figure 4: Eastward

Figure 2: Southward

The current status of the foundation (figures 2 to 5)

Due to the settlement, ground cracking and serious deformation of foundation pit roof in many places, the developer commissioned a testing and appraisal institution to evaluate the safety of the foundation pit of the project. According to the conclusion of the safety appraisal and evaluation report, the integrity of the supporting piles in the site are class I and II piles, and the piles inspected are qualified piles. The basic test ultimate bearing capacity of anchor cable is 275kN (section 3-3 position), acceptance test 17 anchor cables, random inspection load is 234kN, acceptance is qualified. The safety grades of the five evaluation units of foundation pit are as follows: Section 2-2, section 3-3 are Csu, section 1-1, section 4-4, section 5-5 are Dsu.

4. Reinforcement Treatment Design Scheme

4.1 Supplementary work

According to the supplementary survey report (applicable to sections 1a and 4 to 5), the surface of the site is composed of plain fill (Q^{ml}) with alluvial diluvium (Q^{al+pl}) silty clay and quaternary alluvial deposit (Q_4^{al+l}) silt and silty sand. Soil layer parameters are selected according to the main physical and mechanical indexes of each soil layer provided in the geological investigation report, as shown in Table 2.

Soil layer numbering	Severe γ(KN / m³)	Residual shear strength index		Calculated value		Characteristic value of bearing capacity of foundation Fak（Kpa)	Standard value of ultimate bond strength of anchor cable q_{sik} (Kpa)
		Cohesive force Ck (KPa)	Angle of internal friction Φk(°)	Cohesive force Ck (KPa)	Angle of internal frictionΦ(°)		
①Plain fill	17.6	13.99	4.1	13.99	4.1	50	30
②Silty clay	19.3	15.34	5.73	15.34	5.73	150	62
③Silty clay	17.8	13.35	3.67	13.35	3.67	100	45
④Silt	20.6	23.04	12.32	23.04	12.32	150	75
⑤Silty sand	19.7	0.0*	23.0*	5	24	190	95

Table 2

4. Reinforcement Treatment Design Scheme

4.2 Comparison and selection of reinforcement scheme

- Based on the surrounding environment, geological conditions and current construction conditions of the foundation pit, the foundation pit can be reinforced with "internal support" and "anchor cable" support system.
- According to the actual situation of the project, the support type of the foundation pit of the project mainly adopts the "prestressed anchor cable" support structure.

4.3 Reinforcement design of foundation pit

- After the reinforcement measures of "prestressed anchor cable" support and "steel pipe brace" are determined, the foundation pit is subdivided into 12 profiles, and each profile is checked before and after reinforcement. The profile location is shown in Figure 6

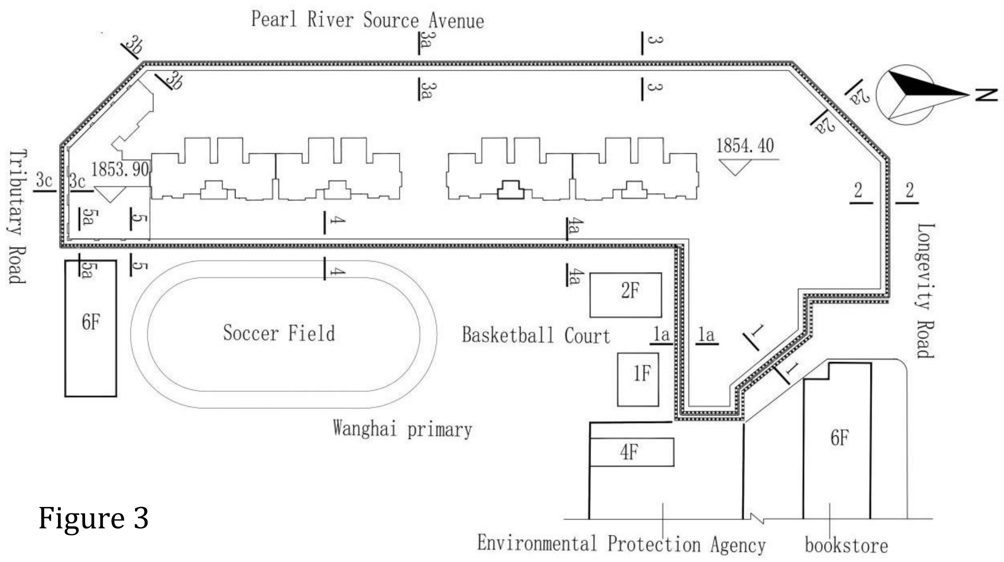


Figure 3

4. Reinforcement Treatment Design Scheme

- According to the Technical Regulations of Building Foundation Pit support, the software "Lizhengdeep Foundation pit 7.0PB3" was selected to carry out the overall anti-sliding stability check calculation, anti-overturning stability check calculation, anti-uplift stability check calculation and stability check calculation of flowing soil for each design section. The allowable values of safety factors for stability check calculations stipulated in the code are shown in Table 3.

Safety factor of anti-overturning checking[k_q]	Safety factor of anti-sliding stability[ks]	Safety factor of anti-heave stability[kb]	Safety factor of fluid soil stability[kf]
1.25	1.35	1.80	1.60

Table 3

4. Reinforcement Treatment Design Scheme

- The results of the stability check calculation before the section is reinforced are shown in Table 4.
- As can be seen from Table 4, when the foundation pit is excavated to the designed depth according to the original support mode and without the inclined steel pipe support, the anti-overturning stability of the foundation pit does not meet the requirements.

Section number	Safety factor against overturning k_q			Safety factor of anti-sliding stability ks	Safety factor of antiheave stability kb	Safety factor of fluid soil stability kf	Result
	Operating condition 1	Operating condition 2	Operating condition 3				
1-1	1.888	1.888	1.054	2.625	5.986	5.324	$K_Q<[K_Q]$
1a-1a	1.747	1.747	0.928	2.662	6.057	4.721	$K_Q<[K_Q]$
2-2	3.078	3.237	1.091	1.838	4.674	2.336	$K_Q<[K_Q]$
2a-2a	3.821	2.163	1.627	1.235	1.066	2.43	$K_s<[K_s]$ $K_b<[K_b]$
3-3	2.54	2.688	1.087	1.931	5.016	2.205	$K_Q<[K_Q]$
3a-3a	2.649	1.591	1.098	1.77	5.019	2.203	$K_Q<[K_Q]$
3b-3b	2.471	1.416	0.966	1.393	1.327	2.186	$K_Q<[K_Q]$ $K_b<[K_b]$
3c-3c	2.695	1.579	1.097	1.929	4.857	2.098	$K_Q<[K_Q]$
4-4	1.787	1.867	0.890	2.069	5.216	2.248	$K_Q<[K_Q]$
4a-4a	1.638	1.707	0.926	1.870	5.249	2.204	$K_Q<[K_Q]$
5-5	1.628	1.250	0.951	1.624	4.013	2.115	$K_Q<[K_Q]$
5a-5a	1.423	1.280	1.038	1.923	4.383	2.233	$K_Q<[K_Q]$

Table 4

4. Reinforcement Treatment Design Scheme

- According to the stress condition and instability degree of different profile positions, the "prestressed anchor cable" with different number of channels is selected.And according to the actual situation to add "steel pipe brace". Take section 4-4 as an example, as shown in Figure 7, it is the original support scheme before section 4-4 reinforcement, and Figure 8 is the support scheme after section 4-4 reinforcement.

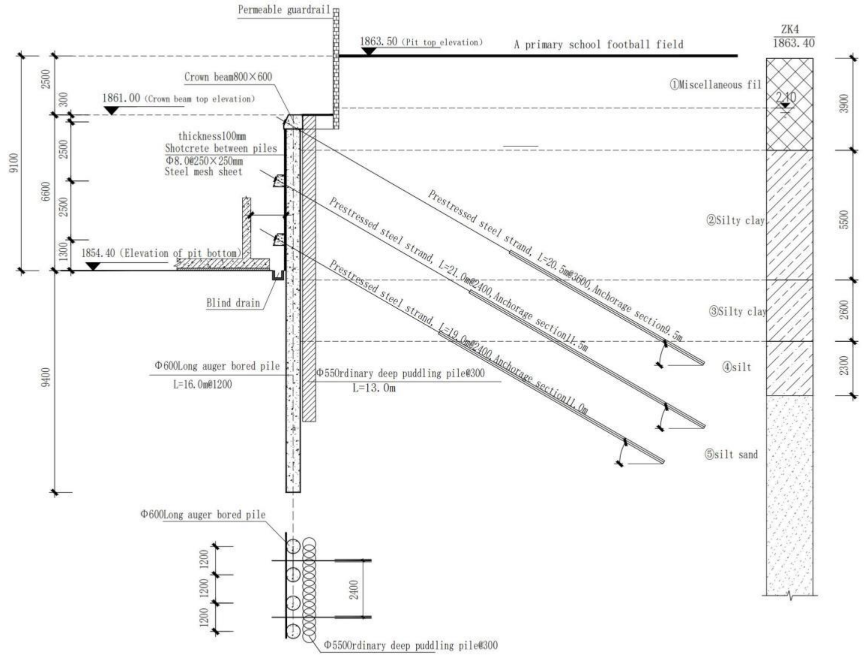


Figure 7

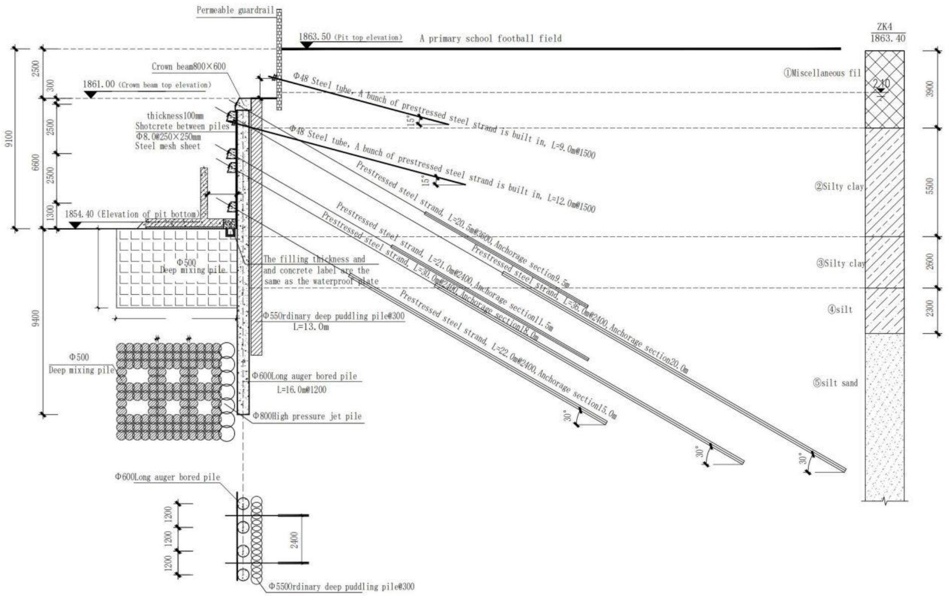


Figure 8

4. Reinforcement Treatment Design Scheme

- After determining the reinforcement support scheme of different sections, the stability check calculation of each section is carried out again to determine the reinforcement measures.According to the empirical calculation, the stability checking results of each section after considering the reinforcement measures are shown in Table 5.

Section number	Safety factor against overturning k_q			Safety factor of anti-sliding stability ks	Safety factor of antiheave stability kb	Safety factor of fluid soil stability kf	Result
	Operating condition 1	Operating condition 2	Operating condition 3				
1-1	1.922	2.402	1.552	2.796	5.986	5.324	
1a-1a	1.744	2.160	1.343.	2.801	6.056	4.721	
2-2	2.800	2.400	2.016	1.964	4.746	2.647	
2a-2a	2.988	2.566	2.095	1.451	4.849	2.430	
3-3	2.453	2.960	1.956	2.066	5.072	2.449	
3a-3a	2.432	2.926	1.923	1.902	5.046	2.444	
3b-3b	2.570	1.955	1.911	1.466	5.122	2.516	Meet the requirements
3c-3c	2.466	1.872	1.819	2.022	4.875	2.297	
4-4	1.971	2.484	1.768	2.206	5.258	2.486	
4a-4a	2.027	2.496	1.736	2.045	5.135	2.442	
5-5	2.047	2.613	1.861	1.943	4.135	2.220	
5a-5a	1.949	1.855	2.122	2.329	4.135	2.220	

Table 5

5. Reinforcement Effect and Conclusion

- Through the monitoring data, it is found that the foundation pit supporting structure after reinforcement is subjected to less disturbance in the subsequent process of earth excavation, and the deformation of the foundation pit is basically in a stable state. The subsequent implementation of the bottom sealing construction of the foundation pit floor is successfully implemented and the construction of the structure roof will continue.
- The surrounding environment of the construction site of this project is relatively complex. In the process of scheme design, combining the existing engineering experience and the original supporting structure, different supporting parameters are adopted to carry out the segmented supporting scheme for the foundation pit. At the same time, the construction has established a sound monitoring system to provide information about support and soil deformation at any time, so as to timely adjust the construction sequence and ensure the safe construction of the project. After the reinforcement, the maximum displacement of the foundation pit wall is within the allowable range of the code, indicating that the reinforcement measures of the foundation pit are successful.