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Treatment Method for a Pile Foundation Accident of 22 Storey Building

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Abstract The original foundation design of a twenty-two-storey building, geological site condition of the foundation, and the appearance of pile foundation accident are described concisely. The treatment method and treatment effectiveness on this pile foundation accident are presented.

Key word pile foundation, deep foundation pit, accident, treatment, and reinforcement design
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1 GEOLOGICAL CONDITION OF SITE AND GENERAL OUTLINE OF ORIGINAL FOUNDATION DESIGN

The ground base of a twenty-two-storey building is located in the first terrace of Yangtze River. There is 2.1 m thick soft ground under the foundation with low bearing capacity and compression modulus. Under the soft ground is a 21～23 m thick sand bed and 0.3～2.2 m gravel. Under 45 m level is medially weatheres rock. The original design of the main structure of this building was as follows. The building consisted of 22 stories on the ground and 1 storey under ground with the structure of frame-shear wall. The plan was 'V'-shaped and the shear wall was placed at the ends and intersection of the two legs of 'V'. The ground elevation of the basement is -4.8 m. The foundation of the building was cast-in-site piles with 800 mm diameter and 36.6 m effective length, and the pile tips reached the gravel. In order to improve the bearing capacity of single pile, the technology of concrete jetting at the tips was used. The tolal number of the piles was 145 and the design bearing capacity of each pile was 5 000 kN. The pile caps were of under-column-isolated type with link beam between them and under-wall-part-raft type. A 500 mm thick water-proof reinforced concrete slab was cast over the caps as the bottom of the basement. The Latticed powder jetting piles and cement mud walls were used as the shoring system of the foundation pit. The length of the powder jetting piles was 10 m. The bodies and tips of these piles were inside the soft ground and placed around the perimeter of the pit or inside the pit where there were not piles.

2 PILE FOUNDATION ACCIDENT

2.1 Accident situation and the results of dynamic low strain detection

During the excavation of the deep foundation pit, some serious damages were found in the pit. Many foundation piles were drifted and inclined in different degrees, and the maximum drift of pile top was 1 240 mm. The quality check was made to the foundation pile by dynamic low strain detection based on one-dimensional bar wave theory with the wave equation as follows.

$$\frac{\partial u^2}{\partial t^2} - \frac{C_0^2 \partial^2 u}{\partial x^2} = 0 \qquad (1)$$

where C_0 is the propagation velocoity of elastic wave

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and also the material parameter of the pile, resulted from density ρ and elasticity modulus E, i.e. $C_0 = \sqrt{E/\rho}$. The equation (1) is a hyperbolic partial differential equation with two different real eigenvalues. The general solution of equation (1) is $U = f(x - ct) \pm g(x + t)$, where "+" is for up wave, "-" for down wave. After pile tips are shocked, the stress wave in the pile would propagate from the top to the bottom, and be reflected and transmited if the wave encounters some defects such as breakdown, crack, necking, mud segregation, and so forth. Therefore, based on the wave amplitude, frequency and velocity of recorded oscillogram, geologic report and construction record, the degree of integrity of the piles could be determined synthetically. The test results showed that only 49 piles were type Ⅰ(perfect), most of the piles were type Ⅱ(little fault), and 6 piles were type Ⅲ (serious fault). The deflection condition is shown in Table 1.

Table 1 The summary of foundation pile deflection

deflection / mm	No.	proportion / %	number of pile "Ⅲ"	effective piles
601～1 240	11	7.59	1	10
361～600	23	15.86	2	21
151～360	57	39.31	1	56
101～150	23	15.86	1	22
0～100	31	21.38	1	30
Σ	145	100	6	139

The drift and inclination of pile were approximately as follows. The movements of the piles around the perimeter of the foundation pit were more than that in the middle of the pit, and most of the drift and inclination of the piles directed to the middle of the pit. Four of the piles of type Ⅲ underlay the raft pile cap under the elevator shaft located in the intersection of the two legs of the V, and 2 underlay the raft pile cap under the strain wall at the end of the left leg of the V.

2.2 Accident analyses

Organized by the department responsible for the work, the reinforcement design group for the building researched the condition of the foundation piles, sufficiently investigated and discussed the problems with the technician concerned in the construction and supervision companies, asked for advices from Municipal Construction Supervision Experts Committee, and took into account the current national code[1～3], then presented the main reasons of the accident specifically as follows.

(1) Shoring system of the foundation pit The powder jetting piles used as the shoring structure were in soft ground. However, during the excavation, most of the piles drifted and inclined to the middle of the pit. The reasons were that the shoring system could not effectively resist the lateral pressure resulting from the soil around the pit, and the lacking of cement in the piles resulted in the low quality of the construction not to meet the design requirements.

(2) Soft soil treatment The soft soil in foundation pit had not been treated and therefore did not meet the requirements of specification [1], which says that reinforcement should be done if bearing capacity of the soft soil around the pile caps is less than 80 kPa. Consequently, the lateral restraint to the piles in deep soft soil was weak and lateral resistance was not enough.

(3) Excavation time When the pit was excavated, the average age of the powder jetting piles was only 10 days. Therefore, the piles were not strong enough to meet design requirement.

(4) Ways of excavation The excavation did not follow the order of layer by layer, and some heavy construction machine working in the pit of such soft soil was not allowable[1].

(5) Influence of tower crane The foundation piles of the tower crane were also in the deep and thick silt, which would have unfavorable effect on the shoring system.

3 TREATMENT OF THE ACCIDENT

Some serious defects were found in many piles with dynamic low strain tests, and the bearing capacity of most of the piles was found to decrease to different degrees with static load and dynamic high strain tests. Therefore, it is necessary to settle down the problem. The treatment of the accident was based on the consideration of safety and the cost. The feasible and concrete measurement to be taken was reinforcement, meanwhile the bearing capacity of the piles could be used. So, it was very important to know the original bearing capacity of the piles before the reinforcement.

The main contents of the reinforcement design were pile supplement , changing isolated caps into rigid monolithic slab cap and consolidation of soft soil.

3.1 Determination of the bearing capacity of original single pile

The bearing capacity of the piles after the accident was determined based on the results of static load test (table 2) , dynamic high strain test (table 3) , the Appendix C of the Technical Specification of Building Pile Construction (J GJ94-94) [1] , and the examination by using probability theory.

Table 2　The static load test of deflected piles

No.	deflection / mm	integrity	limited bearing capacity/ kN
84	570	I	7 000
85	572	II	4 000
86	297	III	7 500

Table 3　The summary of dynamic high strain detection

No.	deflection / mm	integrity	limited bearing capacity/ kN
16	67	I	8 680
32	85	II	8 220
42	521	II	8 620
45	582	I	8 030
47	547	II	8 050
52	63	II	7 450
58	91	I	9 570
65	82	II	9 240
72	202	I	8 080
101	96	I	8 000
116	204	II	9 000
119	361	II	8 150
127	58	II	8 610

(1) By applying the results of static load test and the Appendix C of J GJ94 - 94[1] , the bearing capacity of the drifted piles was obtained as follows.

Q_{um} = 7 250 kN　α_1 = 0.965 517

α_2 = 1.033 48　S_n = 0.048 1 < 0.15

Then , $Q_{uk} = Q_{um}$ = 7 250 kN

The design value of the single pile bearing capacity was $R' = Q_{uk}/r_{sp}$ = 7 250/1.62 = 4 475 kN

where Q_{um} : measured average ultimate bearing capacity ;

α_i : the ratio of measured ultimate bearing capacity to Q_{um} of the ith pile ;

S_n : standard deviation of α_i ;

Q_{uk} : standard ultimate bearing capacity of single pile ;

r_{sp} : comprehensive coefficient of pile side friction and pile tip reaction ;

r_0 : the factor of importance.

(2) By using the results of dynamic high strain detection and the random theory , the bearing capacity of single pile was obtained. The average ultimate bearing capacity S = 8 392 kN , the standard deviation σ = 569.7 kN.

If the assurance rate was taken as 97.73 % , the bearing capacity $N_1 = S - 1.645\sigma$ = 8 392 - 1.645 × 569.7 = 7 457.8 kN (generally , the assurance rate was taken as 95 %) .

Design bearing capacity of single pile was $N = N_1/r_{sp}$ = 7 454.8/1.62 = 4601.7 kN

(3) Design value of the bearing capacity of single pile

By using the less one between R' and N_d , we obtained $R = R'/r_0$ = 4 475/1.1 = 4 068 kN

As to the piles drifting more than 600 mm , based on the dynamic high strain detection , related reference materials , and sufficient discussion , R was taken to 2 000 kN by the reinforcement design group. After considering the advices of the experts invited by design office of construction committee for consulting and appraisement , and the experts of design institute and department of civil engineering in HUST , the reinforcement design group determined the design value of the single pile bearing capacity as shown in table 4.

Table 4　The design value of bearing capacity for deflected single pile

Deflection/ mm	≤150	151～400	401～600	> 600
Bearing capacity/ kN	5 000	4 000	3 600	2 000

In table 4 , the bearing capacity of pile "III" is not included. But as for the piles in non-destructive test inside the pit , the design value of bearing capacity is 5 000 kN.

3.2 Supplementing piles

It was necessary to supplement piles to the building for safety , based on the practical situation of accident as well as the available bearing capacity of the piles. The key factors of pile supplementing were types of piles, location and quantity.

(1) The selection of pile types

Built in rock and cast-in-site piles were used in reinforcement. The diameters and materials of the piles were both the same as the original ones.

(2) Determination of location and quantity of the piles

According to the accident situation, the results of dynamic high-strain, low-strain and static tests were analyzed, and it was found that the drift of the piles were mainly inclination rather than bending. Therefore, the bearing capacity of single pile was not decided by reinforcement ratio. ① The location of the supplemented pile was determined by following principles. The perimeter of the foundation pit was the key region. The reason was that the peripheral piles deflected more seriously and would be used to resist the overturning of the building and to ensure integrity. ②Under all the columns and walls, in some areas where the bearing capacity of the piles were not sufficient, the piles should be supplemented properly, symmetrically and coordinately nearby the original piles. ③ The standby piles should be made nearby type Ⅲpiles.

Based on the bearing capacity of deflected piles and the characteristic of the superstructure, the pile supplementing design was done in the light of the principles described above. Actually, 42 cast-in-site piles whose diameter was 800 mm were supplemented and built in the rock with 1 m depth. At the same time, 21 achor rod static preload piles were supplemented with 377 mm diameter and 20 m length, according to the suggestion of experts of Wuhan Construction Expert Committee.

3.3 Change isolated caps to rigid single-pilce cap

C 30 concrete was used in the rigid single-piece cap, and the thickness is 2.5m. The hidden longitudinal and transverse beams with span-depth ratio less than 3.5, were placed under the columns.

These beams could be regarded as rigid ones. When the settlement occurs, it was considered that the supplemented piles would work together with the original ones, and deform identically. The advantages of this measurement are listed as follows.

(1) It met the requirements of section 3.3.10 in GBJ11-89[2] and Section 7.4.2 in GBJ7-89[3]. It was much capable of adjusting the differential settlement, and improved the integral stability and the competence of overturning resistance.

(2) It was able to coordinate the loading of all piles, and to ensure that the piles would work effectively. In all kinds of load-combination conditions and based on the load-settlement curves, the piles could reasonably distribute the loads to reduce the differential settlement, further, provide good working condition for superstructure.

(3) It was beneficial for solidified soil under caps to give full play to the foundation so as to reduce the loading of single pile.

(4) It would adjust and balance the lateral forces resulted from the irregular deflection of the original piles, and avoid that superstructure had to carry all and part of the lateral forces produced by deflected piles under caps rather than foundation itself[4~6].

(5) The single-piece cap would serve the function of original 500 mm thick waterproof slab. So it was more economic and effective.

3.4 Treatment of solidification of soft soil

The technical standard for building pile foundation (JGJ94-94)[1] stipulated that if the ultimate bearing capacity of the soft soil nearby the pile cap is less than 80 kPa, it is prefered to solidify this soft soil, and in order to guarantee the construction quality of pile supplementing as well as the stability during future re-excavation of the foundation pit, the soft soil should be solidified. Therefore, based on the geological condition, the reinforcement design group presented to treat 6 m thick soft soil under the pile cap specifically with cement-water glass injection[7]. As to soft soil, $f_k \geq$ 100 kPa, $E_s \geq 5.0$ MPa were demanded after treatment. The prospecting of actual situation indicated that the treatment was effective.

4 SAFETY EVALUATION OF THE PIT AFTER PILE SUPPLEMENTING

Our group evaluated the safety of pit after pile-supplementing with positive and converse methods. The pile-foundation design used for the evaluation of pile foundation included: the internal forces at the bottoms of the columns provided by original design office , and the load of partial aerial storey and equipment , exterior walls of basement , side walls of water tank , water, soil rested on the caps outside the basement and caps. The total design value of load is 743 424 kN. In the evaluation , the positive influence of the solidified soil on the bearing pressure of the single-piece cap and the increase in bearing capacity of the pile after the soil solidifying were neglected.

(1) Positive evaluation

With the action of total design loads, the piles were considered to work together with cap. By using the finite element method , it was concluded that the piles with nominal bearing capacity of 5 000 kN actual lywere loaded by 4 400～4 900 kN , the piles with nominal bearing capacity of 3 600 kN actually were loaded by 3 300～3 600 kN , and the piles with nominal bearing capacity of 2 000 kN actually were loaded by less than 2 000 kN.

(2) Converse evaluation

The summation of the bearing capacity of all types of piles was $R = 834\,000$ kN $> \gamma_0 S = 1.1 \times 743\,424 = 817\,766$ kN , in which γ_0 is the of important factor.

From above description , it was known that both the positive and converse evaluation indicated that the bearing capacities of piles were satisfactory , and the safety was ensured.

5 TREATMENT EFFECT OF REINFORCEMENT DESIGN

5.1 Settlement calculation

According to the physical and mechanical properties of the soil stratum provided in geological report , the settlement of all the points in the cap was calculated and the value fell between 28 and 34 mm , and the maximum settlement was 6 mm. It showed that the calculated deformation met the demand of engineering.

5.2 Settlement observation

The construction of the building has been finished. During the construction , we properly fixed up 11 observing points in the building , and observed them throughout the construction. Some of the records are shown in table 5. The data in table 5 were recorded right after the structure was accomplished and the walls of the 17th floor were constructed.

From table 5 , it was seen that the actual settlements are quite satisfactory. Until the structure was accomplished and the construction of walls reached the 17th floor , the maximum settlement was less than 20 mm , and the maximum differential settlement was less than 4 mm. Both of them were less than the calculation results. Although the loading did not reach the design value , the effect of reinforcement was good[8,9].

6 CONCLUSIONS

We obtained more than just this successful reinforcement. The design and construction should be deliberated in advance to avoid any accidents. Once accidents came into being , we should investigate and analyze the causes and effects of the accident carefully , and take safe and economical reasonable measurements. Duringthe disposing of the accident , some other pro-posal were put forward. One of them was supplement piles all around , and the ratio of pile supplement was 90 % (the adopted plan only 28.9 %) , which was safe but costly and needed longer time.

Table 5 Settlement observed value

obseration time	maximum settlement / mm	minimum ettlement / mm	maximum of non-homogeneous settlement / mm	accumulated maximum of non-homogeneous settlement / mm	accumulated maximum of settlement/ mm
1st	1.92(3)	1.04(1)	0.88	0.88	1.92(3)
2nd	1.59(2)	0.25(9)	1.34	1.75	3.42(3)
5th	2.83(3)	0.33(10)	2.50	3.35	8.37(4)
10th	1.01(10)	0.11(8)	0.90	2.77	12.13(3)
15th	0.53(4)	- 0.03($^{7}_{10}$)	0.56	3.63	15.49(5)
20th	1.01(5)	- 0.35(11)	1.36	3.92	18.40(3)
22th	0.79(5)	0.0798)	0.72	3.83	18.75(3)
24th	0.78(2)	0.03($^{3}_{4}$)	0.45	3.91	19.64(5)

Notice : the number inside is the number of measuring point.

Obviously, this plan was not the best solution to the accident. At last, the determination of the implemented plan of the reinforcement presented in this paper resulted partly from the advice and help of local experts, professors and expert committee. In addition, the plan got the recognition and praise of both the client and builder.

REFERENCES

1 Technical specification for building pile foundation (JGJ94-94) [S]. Beijing: China Building & Architecture Press, 1994

2 Design specification for building seism city (GBJ11-89) [S]. Beijing: China Building & Architecture Press, 1994

3 Design specification for building foundation (GBJ7-89) [S]. Beijing: China Building & Architecture Press, 1994

4 Zhao Xi'an. The Reinforced Concrete Structure Design for High-rise Building[M]. Beijing: China architecture and building press, 1992

5 Chen Zhongyi, Ye Shulin. Foundation Engineering[M]. Beijing: China Building & Architecture Press, 1991

6 Zhuo Mingqi, Hu Renli. Pile Foundation Engineering[M]. Beijing: China Railway Press, 1996

7 The edition group. The Collection of Experience in Foundation Treatment[M]. Beijing: China Electricity Press, 1996

8 Zai Jinmin, Zai Jinzhang. The Analysis and Design for High Building Foundation[M]. Beijing: China Building & Architecture Press. 1993

9 Liu Jinli. The Technology of Pile Foundation Engineering[M]. Beijing: China Architecture Material Press. 1996

三峡库区滑坡预测预报 3S 系统关键问题研究

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博士学位论文摘要 三峡水库的形成将面临着水库的正常运行和现有城镇安全的两大方面问题，并突出表现在三峡库区沿江岸坡的稳定性上。利用地理信息系统(GIS)及相关技术手段对“三峡库区滑坡泥石流预测预报 3S 系统”中的关键问题进行了研究，主要工作有如下 7 个方面：

(1) 确立了滑坡地质信息 GIS 可视化空间数据库的建立途径与方法，建立了滑坡体 GIS 地质信息数据库；

(2) 开发了二维地质信息与三维地质信息的相互转化技术；

(3) 确立了地质界面三维插值及滑坡三维地质信息模型建立的新方法；

(4) 进行了滑坡三维地质信息模型的 GIS 工程解析工作；

(5) 利用 GIS 的程序设计语言，探讨了在 GIS 中实现滑坡体稳定性力学解析计算的可行性；

(6) 开发了 GIS 与数值解析系统接口技术；

(7) 探讨了 GIS 在移民选址中的应用。

关键词 三峡工程，滑坡，GIS，3S 系统，预测预报，三维地质信息模型，接口设计

STUDY OF SOME KEY ISSUES ABOUT THE 3S FORECAST SYSTEM FOR LANDSLIDE OF THE THREE GORGES AREA

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