# Research on Incline-Rectifying of Building with Pile Foundation

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## ABSTRACT

Correcting the leaning building with pile foundation, which is very difficult and risky, is a comprehensive management engineering. The studies on incline-rectifying and reinforcement engineering should be prepared according to local condition. An incline-rectifying and anti-retilt reinforcement engineering of coastal building with pile foundation is presented in this paper. The slant reasons of the building are analyzed, the incline-rectifying mechanism with negative skin friction technology is revealed, the design and construction characteristics of incline-rectifying engineering are introduced, the tide influence on incline-rectifying engineering are researched, and the relationships of groundwater, foundation soil, pile foundation and negative skin friction are studied. By this successful project, the experiences have been accumulated for incline-rectifying engineering of building with pile foundation, and good economic returns and social benefits have been yielded.

**KEYWORDS:** Building with pile foundation, Coastal site, Incline-rectifying, Negative skin friction, Tide.

## INTRODUCTION

With the development of economy, the building volume and height are increasing, and the forms of building foundation are quietly undergoing changes. The proportion of shallow foundation is decreasing, but the proportion of deep foundation is gradually increasing, and pile foundation has become the common form of foundation (Hauschild and Wenzel, 1998).

Pile foundation has many advantages, such as high capacity, small uneven settlement, strong ability of anti-liquefaction, broad applicable condition… etc. However, the remedial treatment for pile foundation is much more difficult than that of shallow foundation.

Before the 1990s in China, people had made efforts to the incline-rectifying engineering for shallow foundation buildings (Liu and Ye, 2000). But afterwards, the rapid development of the incline-rectifying technology was applied to deep foundation, especially pile foundation (Liu and Liu, 2000). Tang Ye-Qing rectified one high-rise building of 28 storeys which was 524 mm off-center in 1997 (Xu et al., 1999), and other researchers also started to correct some leaning tall buildings. It is difficult and risky to correct leaning buildings with pile foundation, on which the studies shall be prepared according to practical condition. Therefore, extensive discussion and in-depth study of remedial treatment technology for pile foundation are necessary (Safadoust et al., 2013; Zhu et al., 2005; Burland et al., 2003; Li et al., 2009).

## PROJECT OVERVIEW

### Engineering Background

A seven-storey building with reinforced concrete

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frame structure, which was located on the coast, was studied. The construction area was 3000 $m^2$ and the height was 23.6m. The first storey was for offices, while the $2^{nd}$ to $7^{th}$ storeys were for residence. The cast-in-place pile group foundation was used for the building, which was 480 mm in diameter and had a length of 19 m. The pile tip elevation was -20.0 m and in the medium sand layer. The number of total piles was 116. The pile foundation layout is shown in Fig. 1.

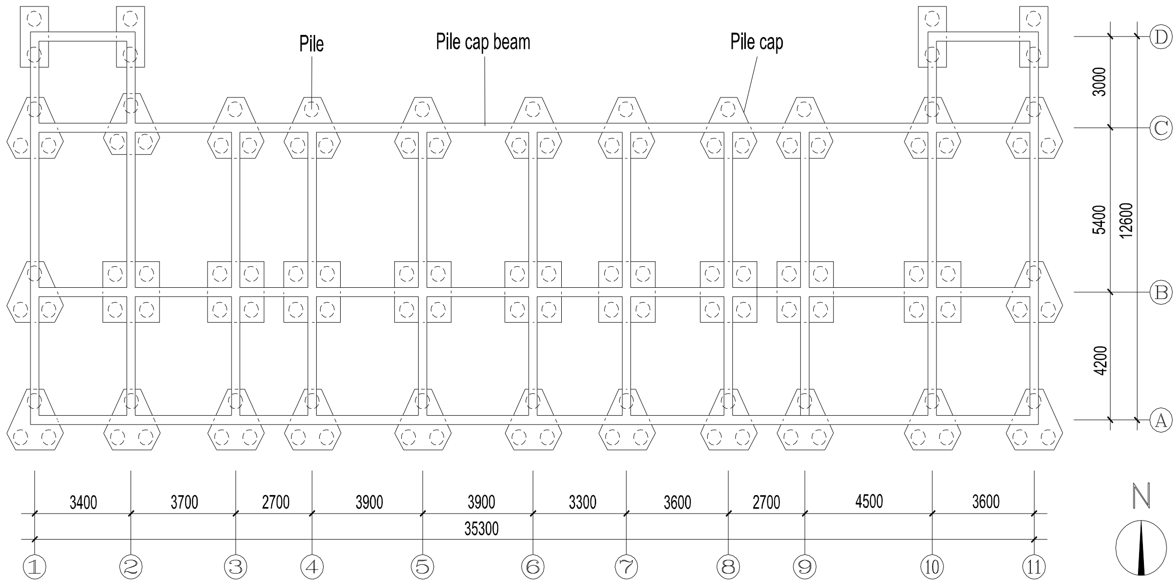


**Figure (1): Pile foundation layout**

The underground water level of the site was -3.50 m. The distribution of soil layers is shown in Table 1.

**Table 1. Distribution of soil layers in site**

| Layer | Soil classification | Thickness m | *C* kPa | *φ*° |
|---|---|---|---|---|
| 1 | Miscellaneous fill | 1.2 | 6 | 4 |
| 2 | Silt (sand) | 1.7 | 8 | 4.5 |
| 3 | Medium sand (containing a small amount of silt) | 2.4 | 2.8 | 27 |
| 4 | Silt (sand) | 2.2 | 17 | 5 |
| 5 | Sandy soft clay | 2.0 | 17 | 5 |
| 6 | Sandy silt | 7.6 | 17 | 2.3 |
| 7 | Clay | 0.7 | 10 | 17 |
| 8 | Medium sand (containing a small amount of silt) | 4.2 | 2.5 | 24 |

There was a neighboring commercial building whose height was 78.2 m and construction area was 36556.8 $m^2$, with two-storey basement. The depth of the commercial building foundation pit was 8.65 m. The pit slope was 57°, which was supported by jet-anchor. The dewatering wells were arranged around the foundation pit, and 5 of them were located near the main building. The well diameter was 800 mm and the depth was 14 m. After the commercial building foundation pile construction was finished, the commercial foundation pit dewatering started, and the water level in the well was under 10 m. When dewatering lasted 68 days, the offset at the top of the main building was 283 mm, visibly leaning north towards the foundation pit.

**Engineering Accident Analysis**

1) The essential cause of the main building lean was the nearby foundation pit deep dewatering and

excavation, on which the underground waterproof curtain had not been built.

2) Under vertical loads, the main building foundation piles had submersion tendency before excavation of near pit, and were supported by pile-side soils the action of which is called upward skin friction; a positive skin friction. According to original design, the vertical bearing capacity of a single pile was 700 kN, in which positive skin friction was 666 kN. Because the foundation pit deep dewatering lowered underground water, some soil above water level had consolidated and caused a downward frictional resistance on the piles; a negative skin friction. The negative skin friction formed a down-drag on the pile shaft (Barnes, 2000; Chen et al., 2011). As the hydraulic slope is a curve, the foundation piles of the main building close to pit (especially foundation piles of the C & D axes) received more down-drag than the opposite side piles (foundation piles on the axis A). Therefore, the foundation piles on the north side (near the pit) had more settlement than those on the south side. The building leaned north.

3) During pit slope construction, anchors were inserted into the foundation piles on the north side, lots of sediments were pouring from drilled holes. The soil and water loss between piles led to the soil collapse, exacerbating the settlement of the foundation piles on the north side (Pan et al., 2002; Yoshimine, 1999).

## INCLINE-RECTIFYING ENGINEERING

### Incline-Rectifying Mechanism

The incline-rectifying method for building with pile foundation consists mainly of the forced settlement method, the lifting method and the comprehensive method. The forced settlement method includes pressure settlement and pile unloading (pile top unloading, pile shaft unloading, pile end unloading, pile cap unloading, negative skin friction).

The incline-rectifying mechanism with negative skin friction technology is as follows: By dewatering beside the original small settlement of the building with pile foundation, the soil above water level consolidates, the effective stress of the soil increases, and the soil gains a significant compression settlement, forming the negative skin friction and down-drag on the pile shaft, forcing the pile settled. Then, the building near the dewatering wells starts to incline. The incline-rectifying mechanism with negative skin friction technology is shown in Fig. 2.

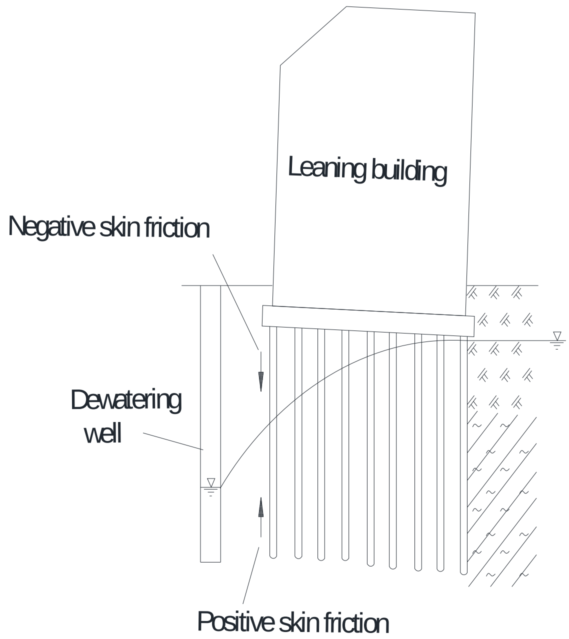


**Figure (2): The incline-rectifying mechanism with negative skin friction technology**

The negative skin friction is calculated as follows:

$$q_{si} = \xi_{ni}\sigma_i \tag{1}$$

where, $q_{si}$ is the characteristic value of negative skin friction for layer $i$ of the foundation soil around the pile; $\xi_{ni}$ is the negative skin friction coefficient for layer $i$ soil, which is associated with the type of soil; $\sigma_i$ is the average vertical effective stress for layer $i$ soil.

**Incline-Rectifying Engineering Design**

According to the building tilt causes and the characteristics of foundation soil, the negative skin friction technology was used to correct the main building.

The forced settlement design value of the building may be calculated as shown below.

$$S_V = \frac{(S_{H1} - S_H)b}{H_g} \quad (2)$$

where, $S_V$ is the forced settlement design value of the building; $S_{HI}$ is the building horizontal offset value; $S_H$ is the horizontal offset design control value; $b$ is the building width along the inclining direction; $H_g$ is the building height above the outdoor ground.

10 dewatering wells were built on the south of the main building outdoor. 5 reinjection wells and 5 observation wells were constructed in the site as well. The15m-long underground curtain for cutting off drains was built between the main building and another building. The dewatering well was 800 mm in diameter, the reinforcing cage of the well was 600 mm in diameter. The dewatering well is shown in Fig. 3.

**Incline-Rectifying Engineering Practice**

In order to further reduce the impact of the surroundings, intermittent dewatering was carried out. The rule of incline-rectifying with negative skin friction technology may be summarized as follows: Each intermittent dewatering period was controlled in the range of 10 h - 15 h. When the water level fell and was kept to 1/2 the pile depth, the building started to lean, the horizontal incline reverting value was approximately 6 ~ 9 mm each dewatering period. When the water level was kept to 3/4 the pile depth, the horizontal return value was about 9 ~ 15 mm. In sand site, the dewatering duration should be determined based on the monitoring data. In addition, the dewatering well should be cleaned up, and the reinjection well should be injected continuously all the day.

Dewatering and incline-rectifying started on April 15th of the lunar calendar (spring tides), the main building started to lean back clearly until the 7th dewatering had finished on April 24th of the lunar calendar (close to neap tides). During that time, the intermittent dewatering occurred 7 times (off and on altogether 10 days), each dewatering period lasted about 6~10h, the water level was kept to -8.0 m ~ 10.0 m, the buildings leaned back slowly and less legularly. However, in approaching the next `neap tide' day, the building tilt-back gradually increased and displayed a good return rule. Figure 4 shows the building tilt-back curve during April 29th ~ May 13th of the lunar calendar, and the intermittent dewatering duration was about 12 h a day, the water level was kept at -13 m.

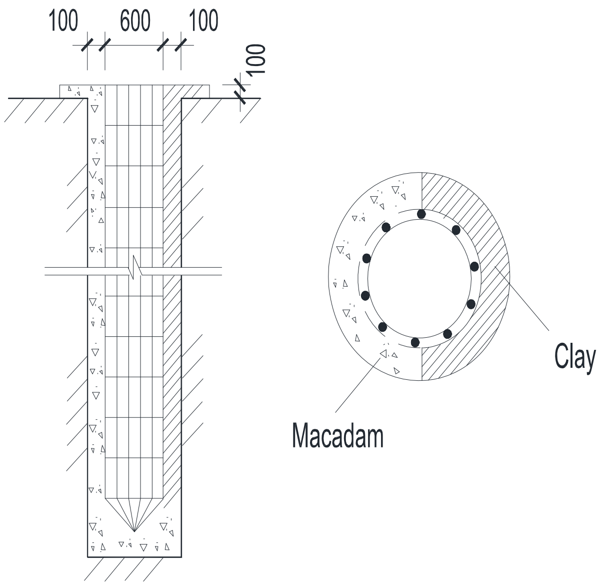


**Figure (3): Dewatering well**

Tide is a natural phenomenon. On the 15th or 16th of the lunar calendar, the tide generating force of the Moon is consistent with Sun's and leads to spring tides in the sea. On the 7th, 8th, or 22th, 23th of the lunar calendar, the tide generating force of the Moon is mutually vertical to the Sun’s, and the sea water appears in neap tides. There is a dynamic seaward boundary in the phreatic aquifer of the coast, its water level rises and falls along with sea water, and tides cause the underground water levels. During spring tides, sea water rises, leading to underground water level rises in coastal formation, and the pore water pressure rises (Zhuang et al., 2006). In this case, the dewatering funnel curve is steep, the negative skin friction is relatively smaller at the same dewatering depth, and therefore, the building tilts reverting at a slower rate. On the contrary, during neap tides, the sea water surface is low, the dewatering funnel curve flattens, and the negative skin friction is relatively bigger at the same dewatering depth, the building returns leaning with a larger rate.

After 2 months of rectification work, the northward lean value of the main building reduced to 63 mm, less than the standards (4%) of the relevant technical codes (Standard of China Engineering Construction Standardization Association, 2007), the structure of the main building was intact, and there was not one new crack. Due to the effective protective measures, the neighboring buildings were not affected in any way.

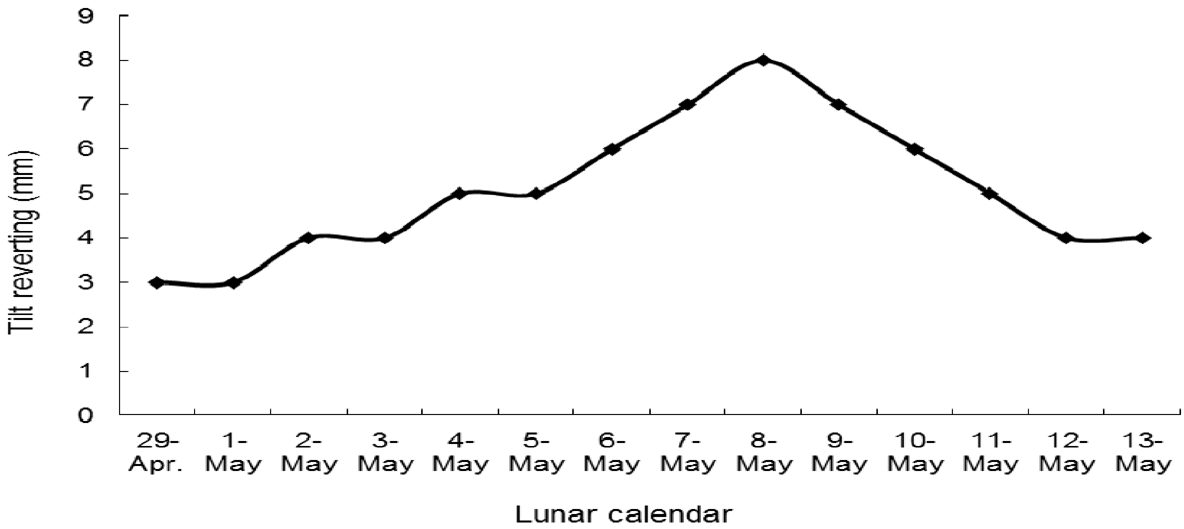


**Figure (4): Tilt reverting curve**

**Anti-Retilt Reinforcement**

Because the bearing stratum of the pile-tips was medium sand, the pile-tips were gradually pressed into the sand during rectification, and the carrying capacity of piles increased little by little. At the same time, the soil around the piles consolidated continuously and became dense, the skin friction of the piles increased. In short, the foundation piles of the main building were reinforced gradually along with the rectification processes. After one year of finishing the rectification, monitoring showed that the main building was extremely stable.

## CONCLUSIONS

It was a successful project example correcting the leaning building of pile foundation with the negative skin friction technology in sandy soft clay, on which good economic returns and social benefits were yielded.

The dewatering well should be slightly deeper than the depth of the foundation pile in general. In the early stages of dewatering, the water level should be dropped to a half of the depth of piles, with dewatering deeply little by little.

The diameter of the reinforcing cage in the dewatering well should not be less than 600 mm to prevent the pump from stucking.

For buildings with long pile foundation, the correcting method of pressure settlement is not desirable in general, the effect is minimal.

The reinjection should be brought into effect all the day during dewatering.

The 'neap tide' beneficial effects should be utilized as much as possible to correct coastal buildings.

## REFERENCES

Barnes, G.E. (2000). "Soil mechanics: principles and practice". 2nd Edition. Palgrave, New York.

Burland, J.B., Jamiolkowski, M., and Viggiani, C. (2003). "The stabilization of the leaning tower of Pisa". Soils and Foundations, 43 (5), 63-80.

Chen, Zhi-jian, Zhang Ning-Ning, and Zhang Xiong-Wen". (2011). "Settlement monitoring system of pile-group foundation". Journal of Central South University of Technology, (6), 2122-2130.

Hauschild, M., and Wenzel, H. (1998). "Scientific background". Environmental Assessment of Products, London.

Li, Q.M., Wang, S.R., Tang, Y.Q., and He, M.C. (2009). "Experimental research on squeezed pan piles in double-row as retaining and protecting of foundation excavation". Rock and Soil Mechanics, 30 (5), 1328-1332.

Liu, Y.C., and Liu, Z.D. (2000). "The rectification of a building by stress relief method". Soil Engineering and Foundation, 14 (4), 29-31.

Liu, Z.D., and Ye, Y. (2000). "Investigation on the latest trend and rectification of Pisa Tower". Soil Engineering and Foundation, 14 (1), 53-56.

Pan, J.L., Goh, A.T.C., and Wong, K.S. (2002). "Three-dimensional analysis of single pile response to lateral soil movements". International Journal for Numerical and Analytical Methods in Geomechanics, 26, 747-758.

Safadoust, J., Amiri, S.N., and Esmaeily, A. (2013). Numerical analysis of reinforced embankment over soft foundation". Journal of Engineering Science and Technology Review, 6 (3), 153-159.

Standard of China Engineering Construction Standardization Association. (2007). "Technical code for moving, incline-rectifying, storey-increasing and reconstruction of buildings". China Planning Press, Beijung.

Xu, X.Y., Tang, Y.Q., and Xu, G.G. (1999). "Inclination rectification and ground stabilization of high-rise buildings". China Civil Engineering Journal, 32 (4), 69-74.

Yoshimine, M. (1999). "Undrained shear strength of clean sands to trigger flow liquefaction". Canadian Geotechnical Journal, 36, 891-906.

Zhu, Y.P., Wang, X.L., and Zhou, Y. (2005). "Theoretical analysis and practice of rectifying reinforcement using expansive method for incline of buildings on collapsible loss". Chinese Journal of Rock Mechanics and Engineering, 24 (15), 2786-2793.

Zhuang Shui-Ying, Chen Juan, and Li Ling. (2006). "Numerical modeling of groundwater table fluctuations due to spring-neap tides in a coastal unconfined aquifer". Journal of Hohai University (Natural Sciences), 34 (1), 10-13.