Research on the Correction of Line-Shaped Structural Buildings

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Abstract. Based on several unpredictable reasons, buildings will have varying degrees of tilt damage. As for Line-Shaped buildings structure, since its own structure has a large aspect ratio, it is more prone to appear the tilt damage than other types of buildings. However, some already existed building correction methods are not suitable for line-shaped buildings. So the present study proposes and analyzes the correction method which is more effective to deal with the tilt damage of Line-Shaped buildings structure. Regarded the ancient the Screen Wall as an example, firstly the study analyzes the reasons of damage, and then puts up with corresponding methods. It can devote an available method for such projects for reference.

Key words: Line-Shaped buildings structure; the Screen Wall; tilt; correction.

1. Introduction

Building tilt is a common phenomenon in building engineering. There are many reasons for building tilt, such as uneven settlement and uneven foundation bearing capacity, all of which will cause building tilting. Wang Dong (2009) analyzed various causes of uneven settlement in buildings, and classified the existing building correcting deviation methods for the tilting problems of buildings caused by uneven settlement, as well as proposed the concepts of active settlement and passive limited settlement, and discussed the mechanism and effect of different correction methods [1~3]. Liu Xiaobo (2015) summarized and compared the development of correcting deviation techniques and put forward the problems and applicable conditions of various correcting deviation techniques at the present stage [4~5]. Lou Haoguang & Zhang Zhesheng, etc. (2006) established a three-dimensional solid finite element model of a sloping brick-concrete building by using the analysis method of structure, basis and foundation interaction, to analyze the settlement development law in the using stage, as well as combined with practice to determine the correcting deviation scheme [6~7]. In terms of ancient architecture, Lv Hengzhu (2005) took Huqiu Tower as the main research object to discuss the causes of uneven settlement deformation of masonry ancient pagoda, and the analysis and simulation methods of reinforcement engineering and monitoring technology [8~10]. The famous Leaning Tower of Pisa is causedby insufficient foundation bearing capacity and groundwater excavation, etc[11~12].

Although the research on the correcting deviation phenomenon of building tilting has been very rich at home and abroad, most of the research objects are still some traditional types of buildings, while the correcting deviation research on the line-shaped of buildings is relatively lacking. The so-called line-shaped of building is the building that has a relatively large aspect ratio. This type of building is

relatively more prone to tilt, so it is necessary to carry out the correcting deviation research of the line-shaped building represented by the ancient screen wall.

2. Reasons for the tilt of the line-shaped building

Because the aspect ratio and of line-shaped structure building are large, its stability is not as good as that of the conventional buildings, and it is more prone to occur tilting damage than the conventional buildings. Therefore, it is necessary to analyze the reasons for the tilt of the line-shaped structure building.

Fig.1 The line-shaped building represented by Screen the wall

The foundation of the building will fall under the action of the superstructure load, and the settlement value is calculated as equation (1):

$$s = \Psi s \sum_{i=1}^{n} \frac{p_0}{E_{si}} (z_i \overline{a_i} - z_{i-1} \overline{a_{i-1}}) \tag{1}$$

In this equation: s is the settlement value of the building foundation, mm; Ψs is also the empirical coefficient; zi is the distance from the base to the soil layer, m; ai is the average additional stress coefficient of the soil layer; Esi is the compression modulus of the soil layer Quantity, kPa; p0 is the additional stress of the base, kPa, which can be expressed by the formula (2)

$$p_0 = \frac{F+G}{A} - \gamma_d d \tag{2}$$

In this equation: F is the load of the superstructure, kN; G is the basis weight, kN; A is the base area, m2; γd is the weighted average of the soil layer from the surface to the foundation; d is the depth value of the base, m.

It can be seen from equation (1) that the direct factors affecting the settlement of the building foundation consist of two parts:

(1) Influence of poor foundation: On the one hand, due to the uneven soil quality of the foundation and the thickness of each soil layer, the compressibility of the foundation soil is not uniform, which will cause uneven settlement of the foundation; On the other hand, the foundation area of this type of building is small and the weight is relatively large, which is likely to cause insufficient bearing capacity of the foundation. This will also cause uneven settlement of the foundation, which is one of the main causes of tilting damage of the building.

(2) Influence of the load: Two loads that are important for the tilt of line-shaped structure building include the self-weight load and the wind load.

Because the aspect ratio and aspect ratio of such building are large, its own center of gravity is relatively high and it is very sensitive to its own verticality, many buildings with similar structure have different degrees of tilting. Especially the structure buildings of masonry materials, often due to their low strength and large self-weight, once the tilting phenomenon occurs, the stress concentration on one

side of the building will lead to eccentric compression, which will accelerate the tilting phenomenon speed of the building.

On the other hand, because the shape of such structure building is similar to that of the screen, once there is a strong wind with the headwind direction, a relatively large wind load will be applied to the building. Similarly, the stress concentration phenomenon will occur on the leeward side of the building, making the building occur tilting damage easily.

It can be seen from equation (2) that among the causes of the settlement of the building foundation, the base area A also has a certain influence on the base additional stress:

(3) It can be known from the geometric knowledge that the area of the bottom surface of line-shaped structure building is much smaller than that of the conventional building. Therefore, the smaller the A in the formula (2), the greater the additional stress on the substrate. For the line-shaped structure building, it is more likely to produce uneven settlement to cause the building to tilt compared with the conventional building.

(4) Influence of water: Water is one of the important causes of damage caused in many buildings. If the drainage on one side of the line-shaped building is not smooth, it will cause rainwater deposition, which will make the foundation part soak in the water for a long time, resulting in the tilt of the building.

(5) Other influences: In addition to the above reasons, the influence of the earthquakes and the construction impact of adjacent buildings, etc., may also cause tilting damage of such buildings.

3. Correcting deviation methods of the line-shaped buildings

3.1. The necessity of correcting deviation

When the line-shaped building is initially tilted, it has little effect on the structure of the building. However, as the further development of silting, it not only affects the aesthetics of the building, but also makes the building collapse. If the inclined building is not corrected in time, the inclination will be intensified and the danger will be increasing day by day, then the manpower and material resources required for the restoration project are greater and the repairing work will be more arduous. Therefore, it is necessary to choose a reasonable method to correct the deviation and reinforce the inclined building.

3.2. Correcting deviation methods commonly used in conventional buildings

At present, many experts and scholars have conducted a lot of research and classification on the correcting deviation methods commonly used in conventional buildings. The correcting deviation methods based on different types of correction methods are classified differently. Here, the correction methods commonly used in conventional buildings are roughly divided into two categories: the forced landing method and the jacking method. The forced landing method refers to use the enforcement action to increase the settlement of the part with smaller settlement volume and balance the settlement volume of the building in a short time. The jacking method refers to jack up the part with larger settlement volume to adjust the settlement of each part of the building, so as to achieve the purpose of correcting deviation [14].

The forced landing method can be divided into the foundation part reinforcement correcting deviation method, water immersion correcting deviation method, borehole soil excavation correcting deviation method, the artificial soil excavation correcting deviation method and water rushing soil excavation correcting deviation method. The foundation part reinforcement correcting deviation method refers to strengthen one side of the foundation with large settlement volume to reduce the settlement of this side, while the other side continues to sink. This method is suitable for the correcting deviation of the building where the settlement is not stable and the inclination rate is not large; The water immersion correcting deviation method is to make holes or grooves in the soil, then soak in water through the holes or grooves, so that the foundation soils become soaking settlement to force the building to sink. This method is suitable for the case of soaking settlement of loess foundation; The borehole soil excavation correcting deviation method is suitable for the soft clay foundation, which uses the drilling machine to drill the foundation soil under the foundation or the side to produce the lateral compression deformation of the

foundation soil; The artificial soil excavation correcting deviation method is to borrow the local soils, or dig wells and holes to take soils, forcing the local additional stress in the soil to increase and aggravating the lateral deformation of the soil. This method is suitable for soft clay foundation; The water rushing soil excavation correcting deviation method uses the pressure water to flush, so that the foundation soil is partially hollowed out, the additional stress of the foundation soil is increased, then the deformation is intensified. It is suitable for the sandy soil foundation or the foundation with the sand cushion.

The jacking correcting deviation method is specifically divided into the masonry structure jacking correcting deviation method, pile pressing reaction force jacking correcting deviation method and high-pressure grouting jacking correcting deviation method. The jacking correcting deviation method of masonry structure is to lift by the supporting beam of the structural wall, which is suitable for the various masonry buildings where the foundation soils and elevations are too low while the whole should be lifted up; The pile pressing reaction force jacking correcting deviation method is suitable for the smaller buildings. First, press enough piles in the foundation, then use the vertical force of the piles as the reaction force to lift the building; The high pressure grouting jacking correcting deviation method refers to use pressure grouting in the foundation soil to produce jacking force to lift the roof of the building, which is suitable for smaller buildings and raft foundations.

3.3. Correcting deviation methods of the line-shaped buildings

Due to the structural characteristics of the line-shaped buildings (the aspect ratio is relatively large), not all correcting deviation methods are applicable to them, so it is necessary to conduct the further study on the correcting deviation methods of the line-shaped buildings.

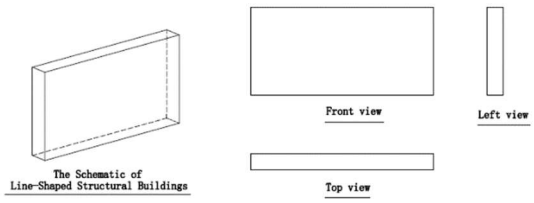

Fig.2 Schematic diagram of the line-shaped building(left)

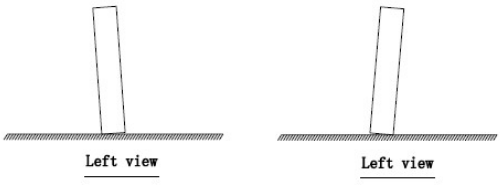

Fig.3 Two cases in which the line-shaped building is tilted(right)

(1) The correcting deviation methods of large-scale construction (pile foundation unloading method, etc.) may have large-scale instruments and equipment during the construction process, and this equipment may be larger than some line-shaped buildings. In addition, some of them need to deal with the large area of the site, then the vibration generated during this process may cause secondary damage to the line-shaped buildings that have titled. These correcting deviation methods are not suitable for the correction of such buildings.

(2) If the water is improperly controlled in the water treatment correction methods, such as water immersion correcting deviation method, water rushing soil excavation correcting deviation method and

precipitation method, it will easily lead to correction failure or even increase the inclination hazard of such buildings. Therefore, this type of method is not suitable for the correcting deviation of the line-shaped buildings.

Pressurization method: Appropriately increase a certain additional stress on the side where the side of the foundation has a small extent of settlement, so as to aggravate the settlement of the building. This method has a specific application scope, which is suitable for the geology with weak soil and the small buildings with small degree of settlement. This method will take a long time to correct the deviation. The tilt arose from the shift of the gravity center can also be corrected by the pressurization method. The the shift of the gravity center can produce a certain offset torque, so a correction torque that is larger than the offset torque is required to balance it. This torque can be calculated by the following formula (3).

$$M = Smax \times K \times F \times (B/3) \tag{3}$$

In this equation: **F** is the base area (unit: m2)

K is the foundation bed coefficient (unit: kN/m3)

B is the width of offset direction of the base (unit: m)

Smax is the average settlement volume, that is, the largest side edge of the settlement (unit: m)

This method can be applied to the correcting deviation of the line-shaped buildings, but it needs to be determined according to the site conditions.

(4) The jacking method. This method can accurately control the correcting deviation volume, fully meeting the requirements of the correction accuracy of the line-shaped buildings. However, this method has a certain influence on the original structure, requiring the original structure to have better overall stability. The jacking correcting deviation method should be operated at the bottom of the foundation. For conventional buildings, the space under the foundation is already limited, and the foundation of the line-shaped building is much narrower than that of the conventional building. Therefore, it is especially difficult to work under the the line-shaped building foundation. Moreover, this method also requires a lot of manpower and material resources, so the jacking method is not suitable for the correction of the line-shaped buildings.

(5) The construction of the excavating soils correcting deviation method is relatively simple and practical. The most important thing is that there is no large vibration in the process, which has no effect on the stability of the building. At the same time, this method can control the correction volume of the building through controlling the diameter, length and direction of the excavated holes, which satisfies the requirements of the correction accuracy of the line-shaped building. Therefore, it is suitable for the correction of the line-shaped building.

3.4. The monitoring method of the line-shaped building

Since the size of the line-shaped building is not large, the monitoring method of it is relatively simple.

Set monitoring points on the wall, use the level meter and connecting tube to observe the settlement, monitor the wall inclination changes by the hanging vertical line and the theodolite and control the correcting deviation speed.

In order to prevent the line-shaped building from occurring the cracks to damage the building during the process of correction, it is necessary to use a strain sensor to monitor the relevant parts of the line-shaped building.

4. Project example application

The screen wall of Zhongyue Temple is located in the Zhongyue Temple at the foot of Taishi Mountain in the south of Songshan Mountain in Henan Province, which is apart from 4 km of the east of Dengfeng City, Henan Province. Zhongyue Temple is the most complete and largest Taoist temple complex in the Five Mountains, which basically retains the regulations of rebuilt after the Qing Dynasty. The screen wall is located in the Zhongyue Temple, which is a part of the ancient architectural complex of Zhongyue

Temple. It is one of the national key cultural relics protection units and one of the heritage sites of historical buildings in the world cultural heritages. In addition, it is also the holy land of the world's Taoist mainstream.

4.1. Analysis of the diseases and causes of the screen wall

The whole screen wall is arranged in a line shaped with hard mountain top and gray tile roof. The total height is about 4.68 meters and the height of the lower Xumi base is 0.9 meters. The wall core is made of square bricks with hard core practice. Imitation wood frame is made in all round and a masonry head with the width of 0.7 meters is built outside the frame.

The overall status of the screen wall is preserved well. However, due to years of disrepair and neglect of maintenance, the roof is partially weedy, almost all of the north slope tube slabs, hook heads and dripping water are lost, the south slope hook head is almost lost, and the vertical ridge is partially damaged. The whole is inclined to the northwest by about 100 mm, as shown in Fig. 2. tilting damage is an important disease of the screen wall in Zhongyue Temple. According to the analysis of the site investigation, the reasons for the tilt of the wall are as follows:

(1) The ground in the northwest direction of the screen wall has a slight depression, so that the rainwater collects here after raining and cannot be discharged in time. The foundation on one side of the wall is soaked in the water, which causes uneven settlement of the foundation, resulting in the tilt of the screen wall.

(2) The wall core of the screen wall is made of a material different from other parts, which make the wall occur an eccentric loading. The stress concentration phenomenon occurs at the lower end of the north side of the wall, which causes the wall at the lower end of the wall to be crushed, resulting in the tilt of the screen wall.

(3) The screen wall of Zhongyue Temple was constructed for a long time. Because the ancient craftsmen often only considered the shape and aesthetic effect of the building, but considered less about the problem of foundation bearing capacity, as well as the foundation area of the wall is small but heavy, the bearing capacity of the foundation is insufficient.

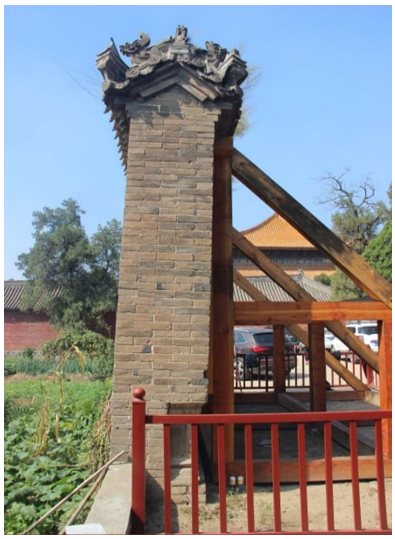

Fig.4 Tilt damage of Screen the wall of Zhong Yue Temple(left)

Fig.5 The bottom of Screen the wall is crushed(right)

4.2. The correcting deviation program of the screen wall

(1) Reinforcement plan

The wall shall be temporarily reinforced before construction. When the correcting deviation reaches to the predetermined position, backfill the soil bin with gravel immediately to reinforce.

The bottom wall foot of the northeast corner of the screen wall is a complicated part with a large load and a relatively concentrated force. If the efflorescence of the brick is too deep or the efflorescence continues to develop, it may weaken the stress surface, then affect the entire structural system. Removing and repairing method can be used. Use the spatula or chisel to remove the efflorescence part, then cut and grind the brick with the same size to inlay in the original place, and then stick it with cement paste or epoxy resin; the crack of the screen wall should be reinforced through infusing water glass.

(2) Correcting deviation program

The screen wall of Zhongyue Temple belongs to the ancient cultural relics building and the principle of "protection first" should be followed in the protection of ancient buildings. Therefore, it should be cautious for the correction and reinforcement of ancient buildings. Under the premise of ensuring safety, its original state should be kept as much as possible. The position of the wall is not a complete flat ground. The south side of the wall is lower than the north side by about 0.5 meters, as shown in Figure 6. According to the correcting deviation method applicable to the line-shaped building and the location site of screen wall of Zhongyue Temple wall, the artificial soil excavation correcting deviation method should be adopted, and its location is very favorable for this correction method.

The amount of soil excavation can be calculated by referring to the following formula (4):

$$V = Smax \times (F/2) \tag{4}$$

Thereinto: **Smax** is the settlement volume (m) required for the base edge correction;

F is the base area.

In order to ensure better results, while preventing the settlement rate from being too fast and beyond the scope, the reduction of the base area should meet the requirements of the following formula (5):

$$2f > p > f \tag{5}$$

Thereinto:**f** is the design value of the bearing capacity of the foundation;

P is the additional stress of the foundation after the base area is reduced.

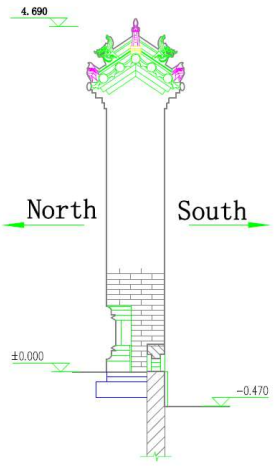

Fig.6 The diagram of the west facade of the Screen wall(left)

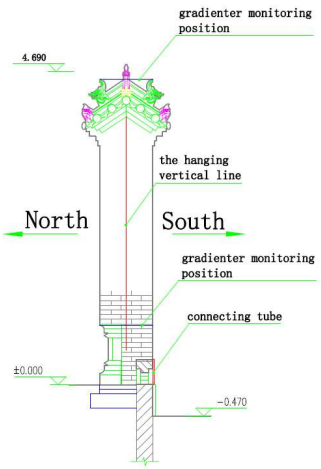

Fig.7 Monitoring position diagram on the west side of the Screen wall(right)

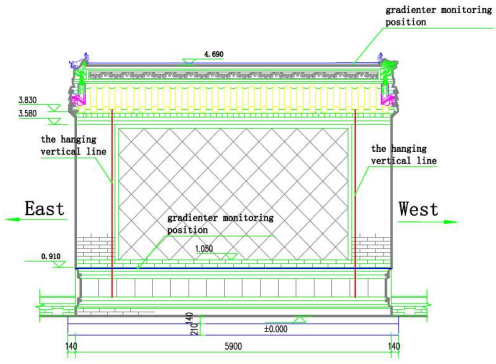

Fig.8 Monitoring position diagram on the north side of the Screen Wall

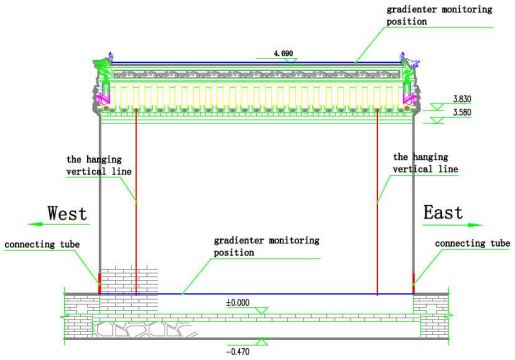

Fig.9 Monitoring position diagram on the south side of the Screen Wall

The specific operation procedure of the program is: temporary support for the screen wall before excavation, excavating the work pit on the south side of the wall. The width of the pit should meet the construction operation requirements and the bottom of the pit should be lower than the base by at least 10-15cm to facilitate soil excavation; Layered soil excavation shall be carried out according to the design requirements, which shall be manually conducted with small shovel, pass bars, iron hooks and steel pipes, etc. If necessary, a flat hole drilling machine may also be used.

(3) Monitoring program

The gradienter and connecting tube is used to observe the settlement in the correcting deviation of the screen wall of Zhongyue Temple, and the hanging vertical line is used to monitor: 5 gradienter monitoring positions; 6 hanging vertical line positions; 2 connecting pipe positions; Respectively set up two gradienter monitoring positions and one hanging vertical line on west and east sides of the screen wall; Respectively set up one gradienter monitoring position and two hanging vertical line positions on each side of the north and south; Set up one gradienter monitoring position along the east and west direction of the center top of the screen wall; Set up connecting pipe position in the north and south corners of the screen wall. The specific locations are shown below:

(4) Waterproofing program

40cm (within the scope of 1m from the screen wall) waterproof layer (20cm) in the ground settlement around the wall; Waterproof method: punning the plain soil →C15 concrete with the thickness of 100mm → leveling by 1:2 cement mortar with the thickness of 20mm → brush base treatment agent with SBS modified asphalt waterproofing membrane with the thickness of 14mm→stick a layer of oil No.350 petroleum asphalt linoleum→C20 fine stone concrete protective layer with the thickness of 80mm; planting soil backfilling with the thickness of 20cm; After the anti-seepage project is finished, the ground around the screen wall is paved with the wall surface practice: punning the plain soil→three-seven ash soil with the thickness of 100cm→ blue brick. The size of the blue brick is 470 mm×240 mm×120 mm.

5. Conclusion

The following conclusions can be obtained through the research in this paper:

(1) The line-shaped building is more prone to occur silting damage compared with the general building due to its size. Therefore, more attention should be paid to the incline damage for such buildings.

(2) Once the line-shaped building is tilted, it will cause more serious damage or even collapse if it cannot be processed in time. Some commonly used methods of correcting deviation methods in conventional buildings are not suitable for the correction of line-shaped buildings; The suitable methods include the stacking press method and the soil excavation method.

(3) The screen wall of Zhongyue Temple belongs to the historical cultural relics building. Considering the old age of the building, the causes of the tilt, the tilting condition and the residual condition, the method of artificial soil excavation in the forced landing method can be used to correct the deviation.

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