Analysis of a Steel Frame Structure in Loess Area for Correcting Deflection and Stopping Tilting Reinforcement

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Abstract: Currently, Surface water infiltration saturates the soil layer of the building foundation, is causing uneven settlement of the pile foundation of the building, resulting in obvious tilting and deformation of the upper main structure. The primary objective of this study is to taking the corrective and stop-tilting reinforcement of a steel frame structure in the humid loess area as the research background, the existing pile foundation is corrected and strengthened by adopting grouted flower steel pipe piles, and the analytical results show that the settlement and deformation of the foundation after grouted flower steel pipe piles reinforcement reduces from 50.3% to 92.83%. This method achieves the purpose of correcting deflection and stopping tilting reinforcement, and meets the bearing capacity requirements of the foundation of the building, and the construction is convenient.

Keywords: Collapsible Loess; Existing Steel Frame Structure; Pile Foundation; Grouting Perforated Steel Pipe Pile; Anti Inclination Rectification and Reinforcement

1. Introduction

Wet subsidence deformation occurs rapidly in wet subsidence loess after water immersion under certain pressure, which is significantly different from loess. Uneven wet subsidence settlement consolidation deformation of wet subsidence loess foundation will cause different degrees of damage to the superstructure of the building, which causes huge economic losses every year [1, 2].

At present, some researches have been carried out on the corrective tilting reinforcement of engineering structures in loess areas, and some meaningful results have been achieved. For example, the treatment of pile foundation tilting accident in soft soil area provides experience [3]. Yuan et al. carried out a study on the corrective tilt-stopping reinforcement of a building with raft slab foundation through a variety of control techniques and achieved the effect of corrective tilt in the end [4,5]. Li et al. took a coal silo-silo structure with a diameter of 22m and a silo height of 40m as the background, and used real-time dynamic adjustment, integrated grouted pile jacking+ drilling and hollowing out + water injection to soften the foundation+ high- pressure rotary spraying piles to reinforce the foundation and a series of process methods to study [6]. Huang et al. Huizhou a hotel as a background, the study of the building foundation using micro-pile reinforcement foundation, broken column jacking method for the implementation of the overall corrective reinforcement as well as the overall corrective tilting, put forward the steel-concrete combined jacking " BuTai of the old and new concrete cross-section of the shear bearing capacity calculation formula" [7]. Zhu et al. proposed the expansion method [8] for buildings in wet subsidence loess areas, utilizing the replacement mechanism of soil between piles and the squeeze mechanism of lime piles, to correct and reinforce the buildings. Wang et al. also corrected and strengthened the buildings in wet subsiding loess area by using the corrective method of reinforced concrete buttress piles combined with water immersion [9,10]. Pei et al. conducted a reinforcement study on stopping tilting of a three-story masonry structure teaching building of a junior high school in a wet loess area [11,12]. However, there are more studies on the deviation correction and reinforcement of existing concrete structures, but there are fewer reports on the tilt-stop deviation correction and reinforcement of existing steel structures in the wet subsiding loess area.

Taking a steel frame structure commercial concrete mixing building roof rise stop tilting and deviation correction reinforcement in humid loess area as the research background, adopting grouting flower steel pipe pile technology to stop tilting and deviation correction reinforcement of existing steel frame structure building in humid loess area, and its research results are of great significance to the future tilting reinforcement of similar engineering structures.

2. Project Profile

2.1 Architectural Profile

This commercial concrete plant mixing building is located in Lanzhou area. It is a 3-story steel-supported frame structure above ground. The total length (axial network dimension) is 11.478m, the total width (axial network dimension) is 5.649m, and the total height is 12.63m (elevation from eaves to outdoor flooring). The steel columns and beams are welded I-beams with bolted connections, and the steel grade is Q235. The walls of the second and third floors are made of double-layer color steel rock wool sandwich panels, and the floor is made of dense-ribbed (sub-beam) steel-paved corrugated steel sheets, and the roof panels are made of double-layer color steel rock wool sandwich panels. The foundation form of the building is mud retaining wall bored pile foundation, the pile length is about 15m, and the holding layer is miscellaneous fill soil.

2.2 Geological Profile

The building exploration depth range from top to bottom is divided into miscellaneous fill soil layer, pebble layer and mudstone layer, of which miscellaneous fill soil: layer thickness of about 30cm ~ 150cm, layer thickness of 978.80 ~ 985.90m. Among them, miscellaneous fill soil: the thickness of the layer is about 30cm~150cm, the elevation of the bottom of the layer is 978.80~985.90m. Pebble layer: the depth of the layer is 16.00~20.70m, the thickness of the layer is 0.60~3.50m, and the elevation of the layer is about 979.60~985.90m. Mudstone layer: the elevation of the layer is 977.60~974.70m, and the burial depth of the layer is 17.20~23.60m. 23.60m.

3. Deformation Analysis

3.1 Deformation Observation of Foundation

Surface water leakage led to the office building and silo foundation is wet state, mixer area is saturated, layer thickness of 16.00 ~ 23.30 m. To the building of the three eaves as a reference surface, through the relative settlement observation and analysis found that the maximum value of the relative settlement difference between the adjacent columns base is 235mm, the upper load-bearing structural components there is due to the uneven settlement of foundation caused by the phenomenon of tilting, seriously affecting the safety of the building.

3.2 Building Tilt Deformation

In order to reflect the lateral tilt displacement of the building due to uneven settlement, a total station was used to observe the lateral displacement of the apex of the corner part of the building as far as the site conditions allowed. Observation statistics are shown in Table 1, through the analysis, the maximum horizontal lateral displacement of the house is 237mm, which is much larger than the steel structure is not suitable for carrying the lateral displacement of not more than H/150" requirements.

Table 1. Lateral Deformation Observation Results (unit: mm)

4/C angle	8/C angle	8/E angle	4/E angle
+80	-130	+123	-110
+190	-237	-196	+180

Note: In the table, "+" means sloping to the inside of the building and "-" means sloping to the outside of the building.

3.3 Damage Analysis

The foundation of the mixing building is mud shielded bored pile foundation, with a pile length of about 15 m. The foundation bearing layer is miscellaneous fill, which belongs to artificially leveled site, with a backfill thickness of about 16~23 m. The backfill soil quality is not uniform, and there is no stratified crushing treatment for the backfill. The bearing capacity of the backfill layer is 70kPa.

Through the analysis of core samples drilled at the site, the water content of the backfill layer increases with the depth, and the area of the mixing building is saturated, which is caused by the infiltration of surface water, resulting in the uneven settlement of the pile foundation of the mixing building. This resulted in the uneven settlement of the pile foundation of the mixing building, which caused obvious tilting and deformation of the steel frame structure of the upper main body; it was also found that most of the steel columns and steel beams nodes, as well as the bolts of the support nodes between the steel columns and the columns were seriously corroded.

Aiming at the damage status quo of the project, the following methods are adopted to correct deflection and stop tilting reinforcement:

(1) The foundation of the mixing building is strengthened to stop tilting, and the plan layout of the grouted flower steel pipe pile is shown in Figure 1;

(2) Remove and replace the deformed steel diagonal braces on the upper part of the mixer building;

(3) Reinforce the steel columns of the third floor whose seismic load bearing capacity is not satisfied.

(4) Carry out anticorrosion and fireproof coating treatment for steel column and steel beam nodes as well as node bolts of steel columns and inter-column supports;

(5) Repair the cracked floor and bearing platform of the mixing building.

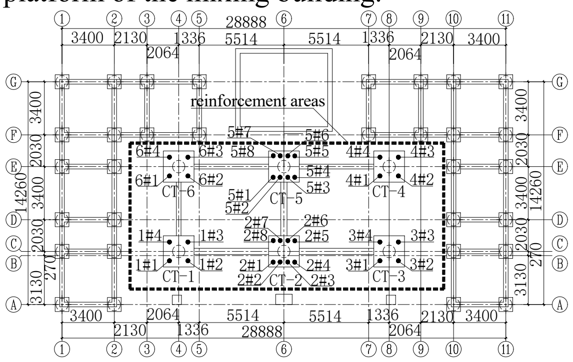

Figure 1. Layout of Stop Tilting Flower Steel Pipe Pile

4. Reinforcement of Tilt Stop and Deflection Correction

After research and analysis, the grouting steel pipe is made of Q235, Ø108, wall thickness of 8mm steel pipe; the schematic diagram of grouting flower steel pipe reinforcement and grouting is shown in Figure 2. The test specimen production steps are as follows:

(1) The diameter, spacing and arrangement of grouting holes are detailed in Figure 2, mechanical drilling is adopted, and the material of grouting pipe is PPR. grouting volume: suspension, 120L ～ 150L per cubic meter of reinforced soil.

(2) Grouting cement adopts P.O42.5 ordinary silicate cement, and water glass is used as additional quick-setting agent, with a mixing amount of 1.5%～3.5%.

(3) Adopt one-time grouting process with water-cement ratio of 1:1; when one-time grouting fails to meet the design requirements, it should be grouted twice.

(4) The grouting pressure is not more than 1MPa, and the radius of grouting diffusion is more than 0.65m.

(5) In the design of the maximum grouting pressure, the grouting flow is not greater than 1L/min, continue grouting for 30min, can end the grouting.

(6) The permissible deviation of verticality during grouting is <1%, the permissible deviation of angle is <1%-1.5%, the permissible deviation of hole depth is +300mm, and the permissible deviation of flow rate is <10L/min.

(7) Grouting should be done in the order of jumping hole interval and periphery first and then center. When the groundwater flow rate is large, grouting should be started from the end with high head.

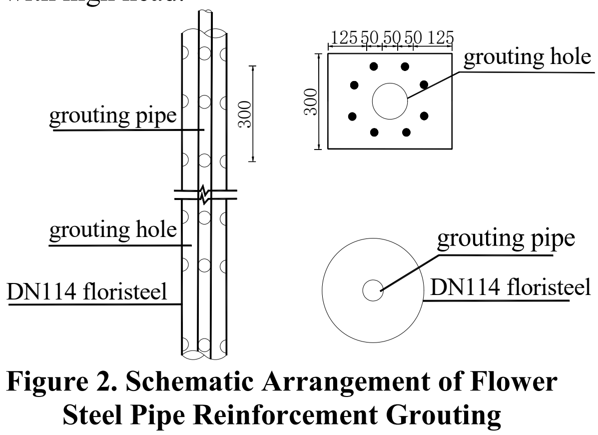

Figure 2. Schematic Arrangement of Flower Steel Pipe Reinforcement Grouting

5. Reinforcement study for Tilt Stopping and Correcting

In order to ensure the safety and reliability of the results of grouting flower steel pipe reinforcement, before the reinforcement construction of three steel pipe piles before and after grouting static load test study of settlement, rebound amount of single pile bearing capacity limit value comparative analysis results are summarized in Table 2, through the six independent foundation under the 32 material Q235, diameter Ø108, wall thickness of 8mm flower steel pipe piles before and after the grouting of the static load test study, the results of the analysis show that the flower steel pipe piles in the The analysis results show that the deformation of flower steel pipe piles after grouting under the same level of load is obviously smaller than that of flower steel pipe piles before grouting; the settlement deformation is reduced by 50.3% to 92.83% compared with that before no grouting, and the bearing capacity is increased by 37% to 114.5%.

Table 2. Vertical Compressive Static Load Test Results of Single Pile after Grouting of Steel Pipe Pile

pile number		pile diameter (m)	pile length (m)	Maximum test load(kN)		amount of sedimentation (mm)		rebound mass(mm)		Limit load capacity(kN)		Limit value average(kN)	
				no grout	grout	no grout	grout	no grout	grout	no grout	grout	no grout	grout
CT1	1#1	0.108	13	252	268	10.83	1.39	3.50	0.72	110	236	110	232
	1#2	0.108	14.5	252	268	10.55	1.53	3.68	0.63	141	236		
	1#3	0.108	11	252	268	9.2	1.25	4.12	0.64	110	220		
	1#4	0.108	16.5	252	268	9.74	1.44	3.51	0.51	157	236		
CT2	2#1	0.108	12	252	268	14.88	1.3	2.5	0.62	126	220	121.88	218
	2#2	0.108	13	252	268	14.83	1.26	3.12	0.61	110	236		
	2#3	0.108	16	252	268	13.94	1.00	1.84	0.35	127	220		
	2#4	0.108	13.5	252	268	13.9	1.21	2.24	0.48	157	236		
	2#5	0.108	13.5	252	268	13.94	1.5	3.91	0.51	110	220		
	2#6	0.108	13.5	252	268	13.40	1.04	2.94	0.34	110	204		
	2#7	0.108	13.5	252	268	11.63	1.65	2.76	0.37	110	220		
	2#8	0.108	14	252	268	12.85	1.9	2.78	0.34	126	204		
CT3	3#1	0.108	13	252	268	9.9	1.8	2.15	0.38	126	204	141.5	224
	3#2	0.108	13	252	268	8.9	1.6	3.01	0.47	126	220		
	3#3	0.108	13	252	268	8.87	1.68	1.41	0.38	157	236		
	3#4	0.108	12	252	268	9.5	1.6	1.35	0.34	157	236		
CT4	4#1	0.108	12	252	268	5.46	1.33	1.01	0.31	126	236	118	224
	4#2	0.108	12	252	268	7.96	1.81	1.24	0.39	110	220		
	4#3	0.108	11	252	268	8.96	1.66	1.34	0.32	110	220		
	4#4	0.108	10	252	268	7.52	1.43	1.28	0.35	126	220		
CT5	5#1	0.108	15	236	252	6.06	1.06	1.54	0.29	126	220	131.75	2222
	5#2	0.108	14	236	252	8.57	1.1	1.29	0.26	126	220		
	5#3	0.108	12	236	252	8.49	1.26	1.28	0.28	157	236		
	5#4	0.108	15	236	252	7.14	1.1	1.02	0.27	141	220		
	5#5	0.108	12	236	252	9.2	1.46	1.98	0.28	126	220		
	5#6	0.108	13	236	252	10.26	1.11	2.97	0.24	126	220		
	5#7	0.108	13	236	252	9.5	1.31	2.92	0.34	126	220		
	5#8	0.108	12	236	252	11.38	0.98	3.27	0.21	126	220		
CT6	6#1	0.108	12	361	377	15.01	1.81	4.96	0.35	183	314	202.5	333.5
	6#2	0.108	12	361	377	16.05	1.42	5.12	0.35	183	345		
	6#3	0.108	14.5	361	377	19.15	1.51	5.74	0.37	252	345		
	6#4	0.108	15	361	377	19.74	1.63	5.76	0.39	224	330		

6. Conclusion

With the background of correcting and stopping tilting reinforcement of a steel structure in a humid loess area, it was found that the infiltration of surface water was the main reason for the obvious tilting and deformation of the steel frame structure of the upper main body caused by the uneven settlement of the pile foundation of the mixing building. By adopting grouting flower steel pipe piles to correct the existing pile foundation and stop tilting reinforcement, the analysis results show that the settlement deformation of the foundation after grouting flower steel pipe piles reinforcement is reduced by 50.3%～92.83% compared with that before grouting, and the bearing capacity is increased by 37%～114.5%. This method not only achieves the purpose of correcting deflection and stopping tilting reinforcement, but also meets the bearing capacity requirements of the foundation of the building, and the construction is convenient. The results of the study provide reference for similar engineering structures in loess areas in terms of deflection correction, tilt-stopping reinforcement and displacement reinforcement.

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Avalilability of Data and Material
All the data and material used to support the findings of this study are included within the article.

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