

The Structure Design and Detailing of a Reconstructional High-Rise Building

Ling Yuhong^{1, a}, Lin BiaoYi^{2, b*}, Ke Yu¹, Chen QingJun^{2, 3, c}

1 Architectural Design and Research Institute of South China University of Technology, Guangzhou 510640, China;

2 School of Civil and Transportation Engineering, South China University of Technology, Guangzhou, 510641

3 State Key Laboratory of Subtropical Building Science, Guangzhou, 510641, China

^ayhling@scut.edu.cn, ^bscutadlin@163.com, ^cqjchen@scut.edu.cn

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Abstract. The practice of structure design and detailing of a reconstructional high-rise building is introduced. To fully utilize the old structure and meet the requirement of the reconstructed structure, measures have been put forward. The enlarging of concrete pile cap and adding strip foundation-beam were used to support the new shear wall added. The enlarging of beam or column sections were used to meet the bearing capacity. The reconstruction of the roof of basement and the application of inclined column were used to the structure optimization. The whole structure analysis shows that the reconstructed structure is safe enough, and the settlement observation shows that the deformation of the whole structure in gravity is small. The design and detailing of the reconstructed engineering is effective and will be valuable to the similar engineering structures.

1. Structural Overview

This project is located in the junction of FangCun of Guangzhou and NanHai of Foshan, and it is south to the Guangfo Expressway. The original project was designed as a synthesize building, which had one storey basement (functioning as equipment room and garage), 12 storeys commercial buildings and two 28 storeys business-living building. The plan of the original project is shown in Fig. 1. The total building area of the original project is about 78,000m². After completing the roof of basement work in December, 1994, the original project was shut down due to various reasons. The project restarted construction in June 2007, and passed the completion acceptance of construction at the end of 2008. At the beginning of the reconstructing, the developers entrusted the Construction Science Research Institute of Guangdong Province to test the safety of the original structure. The results showed that the reconstruction condition was suitable. However, according to the testing results and the new planning of the Guangfo Expressway, this project was redesigned. The new project is divided into two districts, named as A-district and B-district. A-district included three 17 storeys frame-shear wall structure residential buildings, while B-district included four 10 storeys residential buildings. Total building area of the project is about 54,000m², the first storey was the shopping mall, in order to create a large space, the structural transfer floor was adopted on the second storey, which led to a very difference between the new and the old vertical component. The plan of the new project is shown in Fig. 2.

2. Structural Design

According to some references^[1~8], the key problem of reconstruction project is how to coordinate the relationship between demolishing and utilizing the original structure.

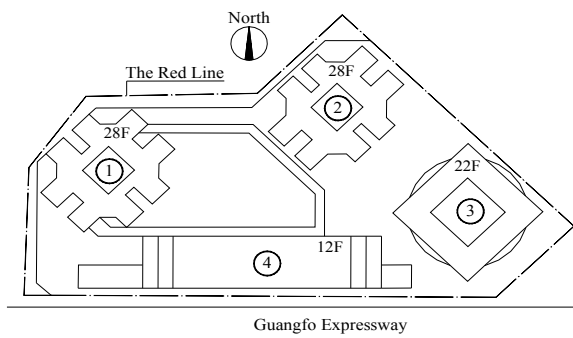


Fig. 1 The plan of original project

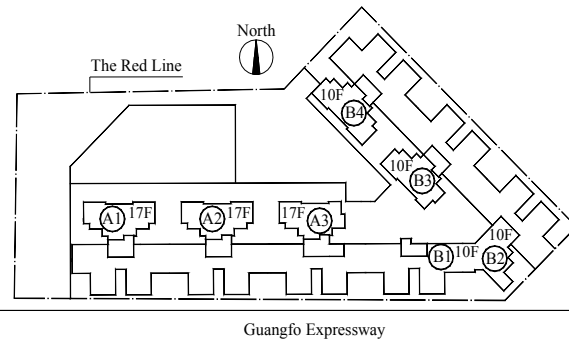


Fig. 2 The plan of new project

Basing on this project, the main difficult is how to fully use the original structure and cope with the difference of vertical component.

2.1. Structure Design of Supporting The Shear Wall

The original structure was designed to be supported by 212 manual hole digging piles, whose bearing stratum was the slightly weathered rock. The new design totally used 179 piles, and the bearing capacity of piles all could meet the requirement, according to the testing results.

However, the design was totally different to the original one, for example, most structure towers was deviated from the original one, and some structure towers had no foundation to support the shear wall above. In order to fully use of the pile foundation so as to reduce the total cost, after coordinating with the architectural technician, two methods were adopted to support the new shear wall.

(1) Adding concrete pile cap to support shear wall

In the original design, there was not large concrete pile cap in B3 tower, so the concrete pile cap was added to support the shear wall above. In the designing of cap, the centroid of the cap should be as close as the centroid of the shear wall. new piles were set under the cap. The thickness of the cap was designed according to the principles of the single pile cap, and the bottom reinforcement was the principles of deep flexural members. One profile of the added concrete cap is shown in Fig. 3.

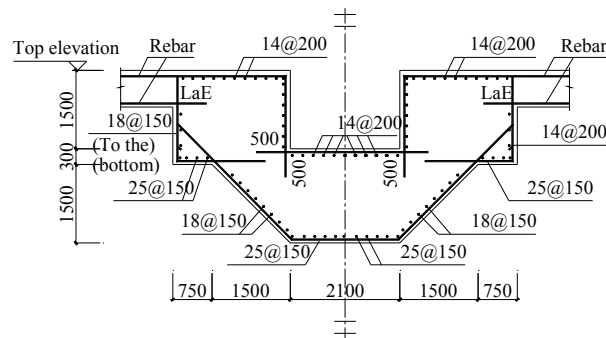


Fig. 3 The profile of the added concrete cap

(2) Adding strip foundation-beam to support shear wall

In order to use the original piles, strip foundation-beam was added on the original piles to support shear wall. The height and width of the strip foundation-beam were calculated by the capacity requirement. By connecting with frame column and pile foundation, the strip foundation beams became a closed system. In order to reduce the torque caused by eccentricity, the centroids of the frame columns or the shear wall should align with the center line of the strip foundation beam. In the design of the foundation beam, firstly, it should be treated as a frame-supported beam to sustain the vertical load; secondly, the moment at the bottom of the column should be included. Furthermore, to ensure the integrity of the supporting structure, the floor was heightened by 180mm on the top of the foundation beam. The foundation beam is shown in Fig. 4.

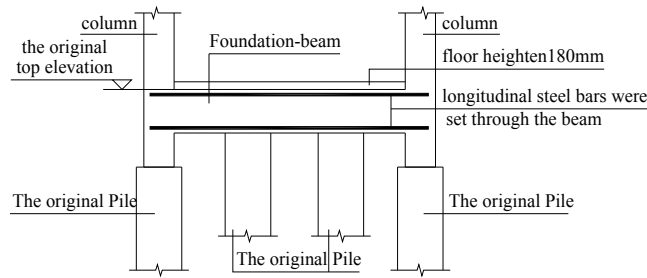


Fig. 4 The setting of foundation-beam

2.2. Structure Design of Meeting The Need of Bearing Capacity

(1) Enlarging the beam section

Because some beams could not meet the requirement for the new design, enlarging the sections instead of demolishing them was a relatively economical and convenient way. The method of enlarging the section of beam is shown in Fig. 5. Firstly, the workers should rough the surface of concrete; the depth of roughing was as same as the steel's protection layer. Then opening stirrups were planted into the beam and weld closed at both ends. The longitudinal steel bars added were not necessary to be planted into column, for the sagging moment of the beam was resisted by the top-bars of original beam. Generally, beams should be heightened more than 200mm and be widened 60mm to 80mm to ensure the quality of pouring concrete.

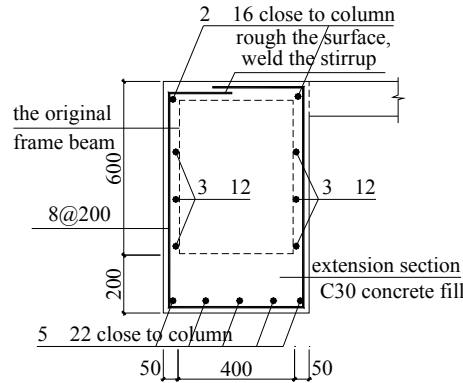


Fig. 5 The method of enlarging the section of beam

(2) Enlarging the column section

The main reason for enlarging the section of column is that the location of column is inconsistent with the new added shear wall above. If the new shear wall is not far away from the column, enlarging the column section can avoid complicate force transferring. The method of larger the column section is shown in Fig. 6. The column can be enlarged in two sides or four sides.

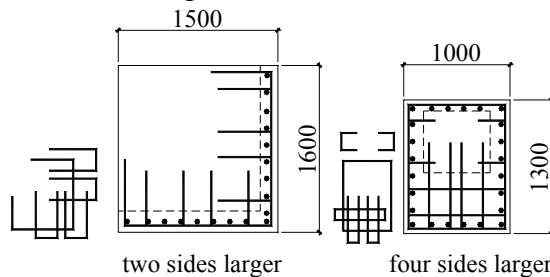


Fig. 6 The method of enlarging the column section

2.3. Structure Optimization

(1) Floor

As mentioned before, the roof of basement had been accomplished when the original project stopped. Many floors were found to be in poor construction quality in the detection of structure. The crack of the floors and the exposed reinforcements were found everywhere. Considering safety and durability of structure, most of the floors were demolished and poured again. Concrete-cutting technique was adopted to cut the whole concrete floor into sections, and small chisel was adopted for demolition near the beam. The top-bars of the floors were cut off and the bottom-bars were retained

800mm from the side of beam. The new floor's surface was 20mm higher than the original one. The new top-bars were set on the above of beam, while the new bottom-bars were lapped with the retained original bottom-bars. The details of the reinforcement of the floors is shown in Fig. 7.

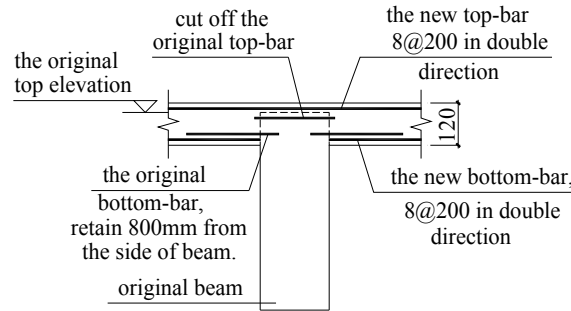


Fig. 7 The reinforcement of the floors

(2) Adopting inclined column for transferring

If enlarging the column section is not economic or has an influence on the building's function, inclined column transferring is a better way to solve the problem. The inclined column transferring is shown in Fig. 8. Because the inclined column will generate a major horizon pushing force, the inclination angle should be controlled and measures should be considered to resist this force. At the roof of basement, the axial force of column can be decomposed to horizon pushing force F_{1X} and axial force of inclined column F_N . F_{1X} is resisted by the roof of basement. The frame beams that connected to the inclined column are under tension-compression stresses at either end respectively, so the longitudinal steel bars should be set through the beam and the corresponding roof of basement should also be thickened.

At the basement slab, F_N can be decomposed to horizon pushing force F_{2X} and vertical pressure F_{2Y} . According to the calculate results, $F_{2X} = F_N \times \cos \beta$, β is the inclination angle. The thickness of the original basement slab is 700mm, and its steel bars are set in double direction through the slab by 20@200 which are checked enough to transmit F_{2X} to the foundation.

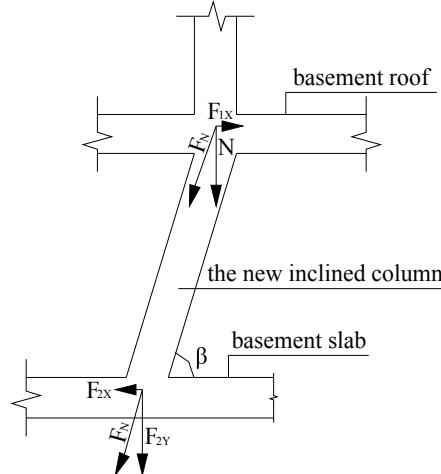


Fig. 8 The inclined column transferring

3. Structure Analysis

In order to accurately analyze the force distributions of the new structure, both software YJK and ETABS are used to conduct the analysis. The fixing of structure is set on the roof of basement, both the translation-torsion coupling and construction load are considered during analysis. The analysis results of the building are listed in Table 1.

It can be seen from Table 1 that the ratio of the third period based on torsion to the basic period based on translation is less than 0.9, the ratio of the maximum inter-storey displacement to the

average inter-storey displacement is less than 1.5, both meet the requirement of the Technical Specification for Concrete Structures of Tall Buildings (JGJ3-2010) ^[9].

Table 1 Vibration characteristics, Displacement and Internal force for building

Items	Sub-items		YJK	ETABS
Vibration characteristic s	Basic period (s) / Translational coefficient		1.2286 /0.96	1.2506/0.99
	Second period (s) / Translational coefficient		1.2251/1.00	1.2117/0.99
	Third period (s) / Translational coefficient		0.9404/0.04	1.0156/0.04
	Third period to basic period ratio		0.765	0.812
Displacement characteristics	Sub-items	Direction(axis)	YJK	ETABS
	Maximum of inter-storey drift (at corresponding storey number)	Earthquake	x	1/2100 (7)
			y	1/2339 (9)
		Wind load	x	1/3727(6)
			y	1/4274 (8)
	Maximum to average inter-storey drift Ratio (at corresponding storey number)	Earthquake	x	1.12 (3)
			y	1.01 (1)
		Wind load	x	1.16 (2)
			y	1.01 (2)
Internal force at bottom of the structure	Shear force (kN)	Earthquake	x	2357.08
			y	2473.65
	Moment (kN.m)	Earthquake	x	69267.98
			y	71345.82
				2403.0
				2553.0
				72360.0
				73280.0

4. Settlement Observation

To observe the settlements and validate the stability of original pile foundation, settlement observation points were arranged near the corner of buildings, marked as “▲”, as shown in Fig. 9. The observation work started on June, 2007 and ended on December, 2008. Four points were chosen to illustrate the settlement, named from C1 to C4, as shown in Fig. 10.

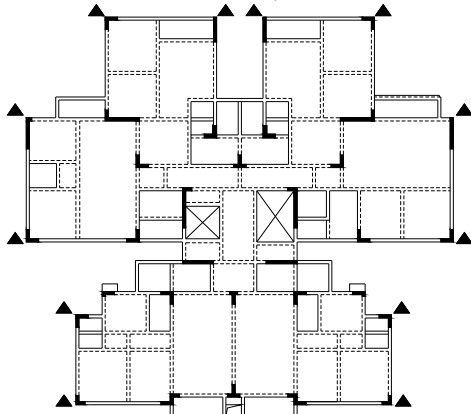


Fig. 9 Settlement observation point layout

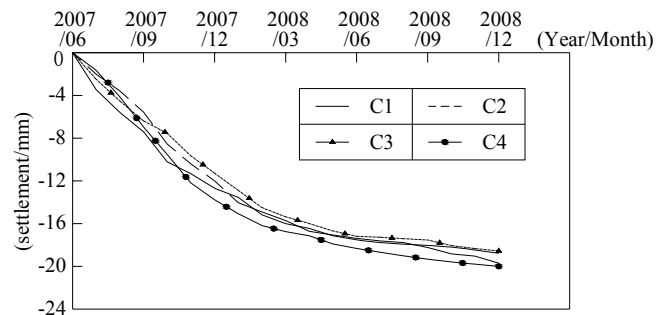


Fig. 10 Settlement curve

According to the settlement observation curve, small settlements were observed. The point C4 showed the largest cumulative settlement, equal to 20.00mm, while point C3 showed the smallest cumulative settlement, equal to 15.10mm. The average settlement of all observation points is equal to 16.32mm. According to the settlement distributions, differential settlements between observation points are small. The maximum differential settlement between point C3 and C4 is only 4.90mm, which is less than the limited value $0.002 L \text{ mm}$ (L is the distance between the adjacent settlement

observation point) according to Code for Design of Building Foundation^[10]. The maximum differential settlement between the last two observations (30 days interval) is 0.18 mm. The settling velocity is equal to 0.006 mm/day, less than the requirements for a building in steady state sedimentation (less than 0.02 mm/day) according to Code for Building Deformation Measurement of Building and Structure^[11].

Up to now, this building have already built up for almost 8 years, but none of bad effects caused by settlement exist.

5. Summary

The reconstruction practice and detailing of a high-rise reinforced concrete frame-shear wall structure is introduced in the paper. To fully utilize the old structure and meet the requirement of the new structure, measures have been put forward. The enlarging of concrete pile cap and adding strip foundation-beam were used to support the new added shear wall. The enlarging of beam or column sections were used to meet the bearing capacity. The reconstruction of the roof of basement and the application of inclined column were used to the structure optimization. The whole structure analysis shows that the reconstructed structure is safe enough to meet all the requirements and the settlement observation shows that the deformation of the whole structure in gravity is small. The above discussion shows the design and detailing of the reconstructed engineering is effective and will be valuable to the similar engineering structures.

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