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Research on the Design and Detailing of a Re-constructional High-rise Building Structure Project Reconstruction

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Abstract: This paper introduced the reconstruction practice and detailing of a high-rise reinforced concrete frame-shear wall structure. To fully utilize the old structure and meet the requirement of the reconstructed structure, certain 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 reconstruction concept detailing of the roof of basement, the enlarging of the beam or column sections and the application of the inclined column are introduced. The whole structure analysis shows that the reconstructed structure is safe enough to meet all the requirement of the designing code and the settlement observation shows that the deformation of the whole structure in gravity is small. The paper shows the design and detailing of the reconstructed engineering is effective and will be valuable to the similar engineering structures.

Keywords: Design, detailing, frame-shear wall structure, reconstruction of structure, settlement observation.

1. STRUCTURE OVERVIEW

This project is located in the junction of FangCun of Guangzhou and NanHai of Foshan, and south of the Guangfo Expressway. The original project is designed as a synthesize building, which has one storey basement (functioning as equipment room and garage), 12 storeys commercial buildings and two 28 storeys business-living buildings. The plan of the original project is shown in Fig. (**1**). The total building area of the original project is about 78,000m^2. 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 restructuring, the developers entrusted the Construction Science Research Institute of Guangdong Province to test the safety of the original structure. The results show that the reconstruction condition is suitable. However, this project is redesigned according to the testing results and the new planning of the Guangfo Expressway. The new project is divided into two districts, namely as A-district and B-district. A-district includes three 17 storeys frame-shear wall structure residential buildings, while B-district includes four 10 storeys residential buildings. Total building area of the project is about 54,000m^2, the first storey is the shopping mall, in order to create a large space the structural transfer floor is adopted on the second storey, which leaded to a great difference between the new and the old vertical component. The plan of this new project is shown in Fig. (**2**).

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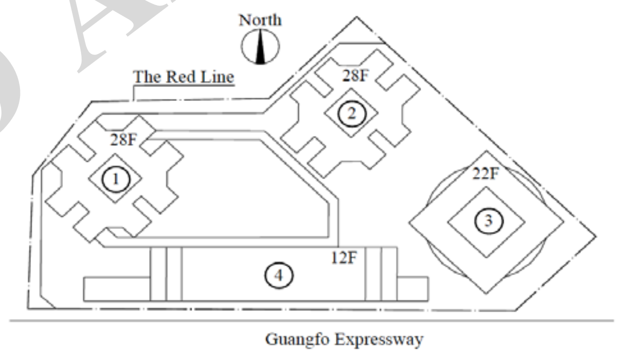

Fig. (1). The plan of original project.

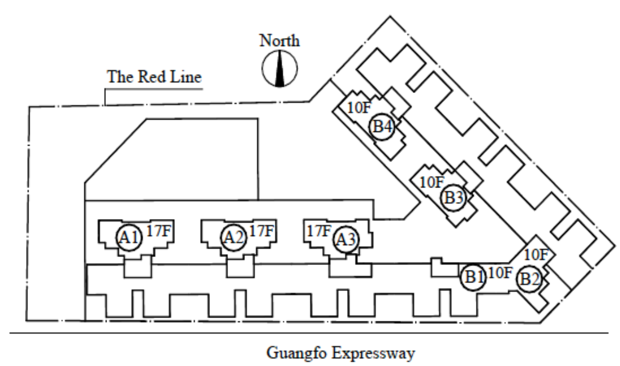

Fig. (2). The plan of new project.

2. STRUCTURE DESIGN

According to some references, the key problem of reconstruction project is to coordinate the relationship between demolishing and utilizing the original structure [1-7]. Basing

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

2.1. Foundation Design

The original project had been designed to be supported by 212 manual hole digging piles, whose bearing stratum is the slightly weathered rock. The new design uses 179 piles instead, and the bearing capacity of all the piles can meet the requirement, according to the testing results. However the design is totally different from the original one. For example, most towers are deviated from the original ones, and some towers have no foundation to support the shear wall above. In order to fully utilize the pile foundation to reduce the project cost, after coordinating with architectural technician, two methods are adopted to support the new shear wall.

(1) Adding concrete pile cap to support shear wall

In the original design, there was no large concrete pile cap in B3 tower, so the concrete pile cap was added to support shear wall above. In the design of cap, the centroid of the cap should be as close as to the centroid of the shear wall. New piles were set under the cap to support the shear wall above. One profile of added concrete cap is shown in Fig. (**3**).

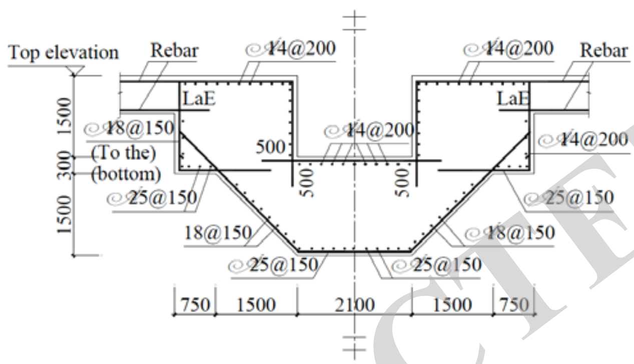

Fig. (3). The profile of added concrete cap.

(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**).

2.2. The Design and Detailing Requirement of the Roof of Basement Structure

(1) Floor

As mentioned before, the roof of basement had been completed when the original project stopped. Many floors were found to be in poor construction quality during the inspection of the 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 chisels were used 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 above the beam, while the new bottom-bars were lapped with the retained original bottom-bars. The details of the reinforcement of the floors are shown in Fig. (**5**).

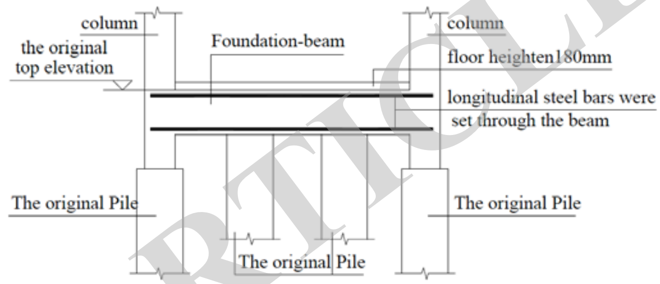

Fig. (4). The setting of foundation-beam.

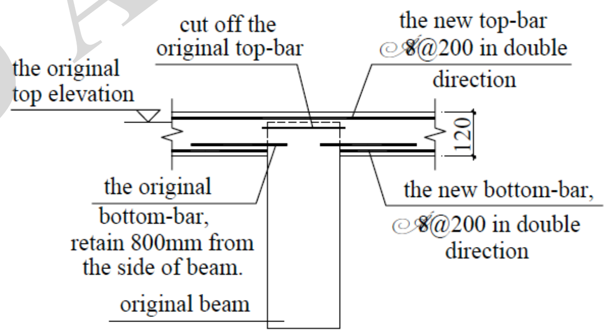

Fig. (5). The reinforcement of the floors.

(2) Enlarging the beam section

Because some beams cannot meet the requirement for the new design, enlarging the sections instead of demolishing them is a relatively economical and convenient way. The method of enlarging the section of beam is shown in Fig. (**6**). Firstly, the workers would rough the surface of concrete; the depth of roughing is as same as the steel's protection layer. Then opening stirrups were planted into the beam and welded close at both ends. The added longitudinal steel bars were not necessary to be planted into the columns, as the sagging moment of the beam is 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.

(3) 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 complication of force transfer. The method of enlarging the column section is shown in Fig. (**7**). The column can be enlarged on two sides or four sides.

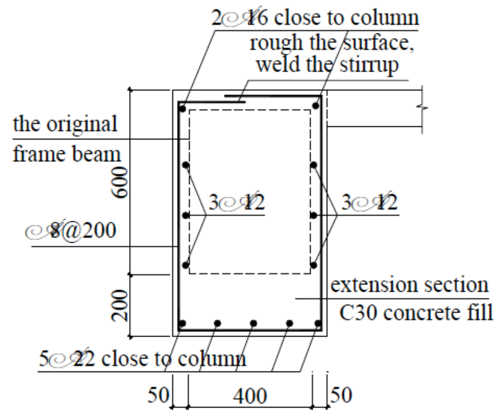

Fig. (6). The method of enlarging the section of beam.

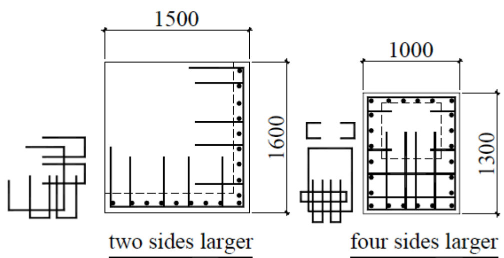

Fig. (7), The method of enlarging the column section.

(4) Adopting inclined column for transferring

If enlarging the column section is not economical or has a detrimental 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 horizontal 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 horizontal pushing force F_{1X} and axial force of inclined column F_N. F_{1X} is resisted by the roof of the basement. The frame beams that are connected to the inclined column are under tension-compression stresses at either ends, 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 horizontal pushing force F_{2X} and vertical pressure F_{2Y}. According to the calculation 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 byM̂20@200 which are enough to transmit F_{2X} to the foundation.

3. STRUCTURE ANALYSIS

Reinforced concrete frame-shear wall structure was adopted in this reconstructed building. In order to meet the utilization need of the first floor and basement, frame supporting columns are set in the first storey and basement, while the transferring storey was arranged in the second storey.

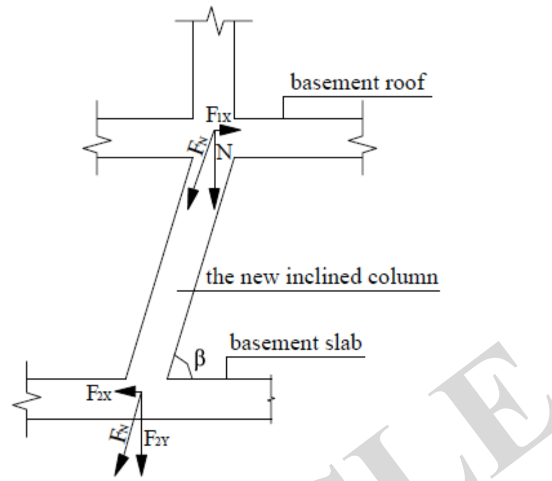

Fig. (8). The inclined column transferring.

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, and 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, and both meet the requirement of the Technical Specification for Concrete Structures of Tall Buildings (JGJ3-2010) [8].

4. SETTLEMENT OBSERVATION

To observe the settlements and validate the stability of original pile foundation, settlement observation points are 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**).

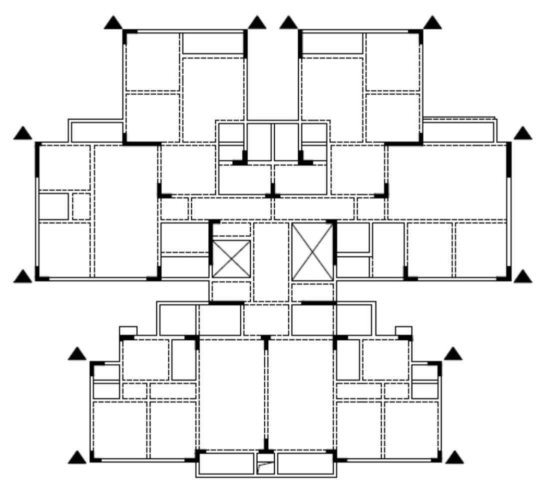

Fig. (9). Settlement observation point layout.

Table 1. Vibration characteristics, Displacement and Internal force for building.

Items	Sub-items			YJK	ETABS
Vibration characteristics	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)	1/2139 (6)
			Y	1/2339 (9)	1/2499(9)
		Wind load	*X*	1/3727(6)	1/4108(6)
			Y	1/4274 (8)	1/4143 (9)
	Maximum to average inter-storey drift Ratio (at corresponding storey number)	Earthquake	*X*	1.12 (3)	1.28 (2)
			Y	1.01 (1)	1.08 (2)
		Wind load	*X*	1.16 (2)	1.06 (3)
			Y	1.01 (2)	1.03 (1)
Internal force at bottom of the structure	Shear force (kN)	Earthquake	*X*	2357.08	2403.0
			Y	2473.65	2553.0
	Moment (kN.m)	Earthquake	*X*	69267.98	72360.0
			Y	71345.82	73280.0

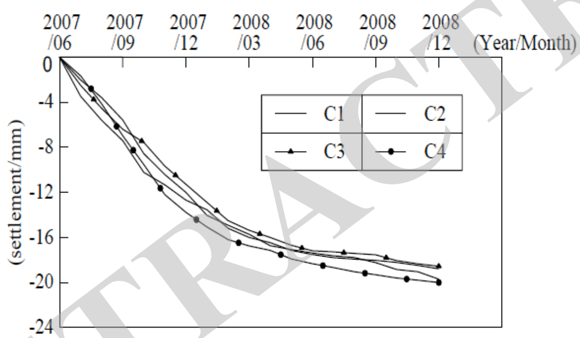

Fig. (10). Settlement curve.

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 mm (L is the distance between the adjacent settlement observation point) according to Code for Design of Building Foundation [9]. 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 [10].

Up till now, this building has been in existence for almost 8 years, but none of the adverse effects caused by settlement exist.

SUMMARY

This paper introduced the reconstruction practice and detailing of a high-rise reinforced concrete frame-shear wall structure. To fully utilize the old structure and meet the requirement of the new structure, certain 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 reconstruction concept detailing of the roof of basement, the enlarging of the beam or column sections and the application of the inclined column are introduced. The whole structure analysis shows that the reconstructed structure is safe enough to meet all the requirement of the designing code 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.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

ACKNOWLEDGEMENTS

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