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Research paper

Application of comprehensive reinforcement technology in high-rise building

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Abstract: In the structural reinforcement of a high-rise residential building in Changzhou city, Jiangsu province, China, the technology of prestressed steel bar strengthening shear wall, which was initiated in China, was applied. Combined with the engineering quality inspection report, the project characteristics and the requirements of the construction party, various methods, such as increasing cross-section reinforcement method and staged replacement concrete reinforcement method, were comprehensively used to treat and reinforce the structures with different quality problems and different parts. In general, the stress and strain of the newly added part always lags behind the stress and strain of the original structure. This will cause the stress of the original structure is too high and the deformation is large, while the stress of the new part is still at a low level, which cannot fully play its role and its due reinforcement effect. Prestressed steel bar reinforced shear wall technology, through the prestressed steel bar on the prestressed steel bar, which is a good solution to this problem, avoid the phenomenon of stress lag, and ultimately not only shorten the construction period of reinforcement, but also ensure the quality of reinforcement and user use area, successfully passed the reinforcement special acceptance. The monitoring data also proved that the reinforcement measures adopted are safe, reliable and economical. This paper can provide reference for the effective development of similar reinforcement projects.

Keywords: Comprehensive reinforcement technology, High-rise building, Prestressed steel bar reinforcement method, application.

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1. Introduction

1.1 Literature review

On the basis of the reliability test and appraisal of the original concrete building structure, the strengthening technology of concrete structure adopts scientific and reasonable methods and measures to strengthen the structure or component in question, so as to improve the safety and durability of the building structure or meet the normal use function of the building within a reasonable service life, and extend the safe service life. With the innovation and development of technology, several methods gradually have been formed in the process of strengthening and transforming concrete structures, for example: increasing cross-section reinforcement method, outsourcing steel reinforcement method, prestressing reinforcement method, sticking steel plate reinforcement method, adding fulcrum reinforcement method, replacing concrete reinforcement method, winding reinforcement method, sticking fiber composite material reinforcement method, and changing the force transmission path of structures and so on. Wu et al. (2017) studied the mechanical behavior changes of reinforced concrete columns strengthened with steel plates. The calculation shows that the bearing capacity and stiffness of reinforced concrete columns strengthened with steel plates have been significantly improved, and the bearing capacity of reinforced concrete columns with smaller width and spacing of steel plates is higher when the amount of steel plates is the same [1]. Yan Xuefeng and Chu Shaohui (2019) studied the strengthening technology of concrete structure with steel plate [2]. Wen bin, Li Chuntao, Zhang Jizhu et al. studied the effect of replacement concrete method on the reinforcement of concrete quality defects [3-5]. Si Jianhui et al. carried out the finite element analysis and experimental research on the seismic performance of damaged concrete columns strengthened with wire wrapped cage, and concluded that the seismic performance of concrete strengthened with wire wrapped cage is better than that of axial and circumferential wire wrapped cage [6]. Wei Chenghui systematically summarized the research progress of building structure strengthened with fiber composite materials [7]. These methods, which have achieved some success combined with the specific engineering practice have their own characteristics and advantages, but in the engineering practice, we should choose the corresponding reinforcement methods from the economic, reasonable, safe and reliable point of view for different quality problems.

Prestressed steel bar, also known as steel bar for prestressed concrete, has the advantages of high strength, high toughness, low relaxation, strong binding force with concrete, good weld ability,

upsetting and material saving. It has been widely used in the manufacture of prestressed components of large bridges, highways and rock mass anchorage at home and abroad. Some scholars have also carried out continuous exploration, Yao Yi studied the application of prestressed steel bar in roadway support [8]. Deng Ming et al. studied the effect of using prestressed steel bars to strengthen the diaphragms of T-beam bridges [9]. Wu Zhenghua also studied the application of unboned prestressed steel bar in bridge construction, however, no one has applied this method to the reinforcement of concrete structures.

In this research paper, we combined the reinforcement practice in a high-rise residential building to discuss and analyze the reinforcement technology of concrete structure, such as prestressed steel bar method, enlarged section method and replacement concrete method, hoping to provide reference and effective development of similar work.

1.2 Overview of engineering case

The high-rise residential building in Changzhou, which has 24 floors above ground and 2 floors below ground, is 98.900m high. The main structure of the project has been capped, the in-filled wall of the upper structure has been built, and the floor cast-in-place slab leveling layer has not yet been constructed. When the quality supervision station rebounded the field structure of the project, it was found that the rebound strength was lower than the design strength value, and the concrete parts with quality problems were locked through batch inspection by the inspection unit: most of the shear wall and column concrete strength below the 12th floor of the residential building was lower than the design strength and had great discreteness, and the structural reinforcement was required after the recheck and calculation by the design unit; no abnormality was found above the 12th floor.

2. Reinforcement scheme design

The structural reinforcement design idea is presented as below [10]. The measured strength of the shear wall concrete in this project is mostly above C25 while very few walls are between C20 and C25, and a considerable proportion of the measured strength of the shear wall concrete is above C30. Considering that the commonly used replacement concrete reinforcement method has great damage to the original structure, and the shear wall after replacement is subject to secondary stress. Not only the stress lag is obvious, but the construction period is long; if it is adopted, the practice of adding steel plate or section steel around shear wall and column will affect the later decoration construction of residents. If the method of adding steel plate or section steel on the periphery of

shear wall and column is adopted, the later decoration construction of residents will be affected. After communicating with the construction unit and considering the characteristics of the project, it is decided to deal with the shear walls and independent columns which do not meet the requirements of structural review according to the following methods.

(1) The increasing (thickening) section method is preferred for reinforcement for the shear wall and independent column located in the basement from the first floor to the second floor, and the reinforcement of the component is calculated according to the actual section size of the component after that. This reinforcement only considers the effect of increasing the section, and does not consider the effect of strength improvement of post cast high-strength concrete (that is, the reinforcement is still calculated according to the measured strength of shear wall and column concrete).

Fig.1 Site diagram of steel bar column

(2) It is proposed to add Φ 100 steel bar column (Q345, Fig. 1) in the shear wall to solve the problem of insufficient axial compression ratio for which the shear wall cannot be reinforced by increasing section method. When the steel bar is installed in place, the prestress calculated by design is applied by jacking to improve its stress lag.

(3) It is proposed to adopt cement-based grouting material (28 day compressive strength ≥ 60MPa) replacement method (pre-setting temporary jacking unloading) to deal with the shear wall which cannot be strengthened by enlarging section method or adding prestressed steel bar column method. Considering the secondary mechanical characteristics of replacement method, the second method (Fig. 2) is adopted in the structural recheck, the original design concrete strength is still adopted.

The shear wall with larger peripheral axial compression ratio is appropriately reinforced because of the displacement shear wall is unloaded to the peripheral shear wall of the same floor.

3. Construction technique

3.1 Shear wall and column reinforcement method with enlarged section

(1) Construction technology

Positioning and setting out → removal of construction obstacles → roughening treatment of component surface → drilling and planting reinforcement → binding and welding of reinforcement → formwork installation → grouting material pouring → formwork removal → maintenance → construction quality acceptance.

Fig.2 Site diagram of shear wall enlargement method

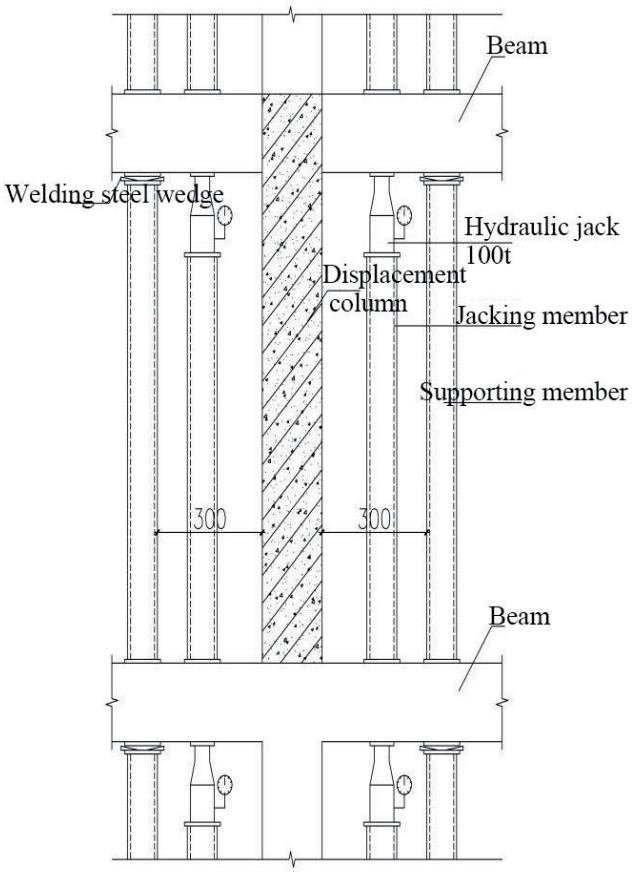

Fig.3 Schematic diagram of shear wall and column displacement method

(2) Technical points

① Roughening

The shear wall and column for strengthening concrete are located on the second floor and the first floor of the basement. The concrete strength of the reinforcement part of the shear wall and the hidden column is relatively low. When roughening, small electric pick is used to roughen, so as to minimize the damage to the original structure. According to the design requirements, the concave convex degree is ≥ 6mm.

② Rebar planting

Rebar planting shall be carried out according to the following procedures: setting out → drilling → hole treatment → hole drying → rebar surface treatment → glue mixing → glue pouring → rebar planting → fixed maintenance. After drilling, the foreign matters in the hole should be removed by using air pump or high-power vacuum cleaner with a pipe extending into the hole for blowing and suction. If there is oil stain in the hole, the wall shall be cleaned with acetone. At the same time, the water shall not be washed to avoid the residual water in the hole weakening the function of the adhesive. JK series planting glue is used for planting steel bars, and special manual syringe is used for gluing. The glue is injected from the bottom of the whole outwards. When inserting the reinforcement, it needs to rotate by hand. The up and down actions should prevent the occurrence of bubbles and make the hole wall fully bonded with the reinforcement.

③ Cushion block setting

After the reinforcement bounded, the cushion block of the protective layer shall be set according to the specification requirements, and the thickness of the protective layer of the outermost stressed reinforcement shall be 25mm according to the design data. The binding of reinforcement shall be completed in time according to the progress requirements of the construction area, so that the reinforcement works and other construction processes can be smoothly overlapped.

④ Formwork cleaning

Before pouring the cement-based grouting material, the garbage in the formwork shall be cleaned up. The new and old interfaces and formwork shall be watered and wetted, and the pouring can only be carried out after the concealed acceptance is correct.

⑤ Supervising

During the construction process, the mark of grouting materials shall be strictly controlled to prevent misuse. The continuity of the grouting materials shall be ensured during the pouring, and during which assigned person shall be responsible for knocking and vibration to prevent cracks, honeycombs and pockmarks. The specially assigned person shall be arranged for timely maintenance for the components that have been poured.

3.2 Shear wall and column replacement

When the shear walls and columns need to be replaced (Fig. 3), hydraulic jack is used to apply the jacking force to the upper structure through the temporary steel pipe. When the requirements of the design unloading force value are met, supporting steel pipe are used to replace them. After all supports are installed and the unloading force is reached, the jack shall be withdrawn. The axial

force of replacement wall and column is obtained by the measured value of axial compression ratio and concrete strength of the replaced vertical member, and the unloading force is obtained by dividing the axial force of replacement wall and column by the number of unloading supports.

(1) Construction technology

Positioning and setting out → removal of construction obstacles → installation of steel pipe support frame for temporary jacking inside → installation of hydraulic jack → installation of monitoring system → Jack grading and pressurizing to required load → installation of fixed steel unloading support outside (it can be installed and fixed synchronously with steel pipe support frame for temporary jacking) → tapping steel wedge until the reading of jack oil pressure gauge is zero → welding steel wedge with upper and lower iron plates → inside Remove the side temporary support steel pipe → remove the concrete → adjust the original reinforcement → install the formwork → pour the grouting material → remove the formwork → maintain → inspect the construction quality → remove the external fixed steel support.

(2) Technical points

① Positioning and setting out

According to the drawing requirements, the laying position that temporary lifting steel pipe support frame and external fixed steel pipe support frame is determined.

② Temporary jacking installing

The Φ100mm×8mm unloading steel pipe that upper and lower ends of the steel pipe shall be firmly welded with the base plate is erected. Leveling instrument and theodolite are used to strictly control the level and verticality of the contact surface of the erected steel pipe.

③ Hydraulic jack installing

100t hydraulic jack with oil pressure gauge is installed, pressurize it slightly until it is squeezed tightly and firmly with the base plate, and pay attention to make the center of gravity of Jack and jacking component coincide, so as to avoid eccentricity during loading.

④ Unloading

According to the requirements of the special unloading plan, the jacking force shall be applied step by step, and the stress-strain observation device shall be used synchronously to monitor the whole process, so as to ensure that the jacking force applied meets the unloading requirements without affecting the safety of the original components.

⑤ Outer fixed steel pipe installing

After the lifting force is applied and stabilized, the outer fixed steel pipe support frame should be installed.

⑥ Steel wedge installing

After checking the levelness and perpendicularity of the fixed steel pipe support frame, the steel wedge shall be used to knock into the gap between the upper iron plate and the base plate of the steel pipe, and the steel wedge on both sides shall be continuously knocked until the reading of the jack oil pressure gauge on the inner jacking support frame returns to zero, and then the steel wedge and the upper and lower base plates shall be welded firmly.

⑦ Concrete crushing

After the concrete is removed, the reinforcement shall be retained. When chiseling, the disturbance to the adjacent components shall be minimized, and the damage to the reinforcement in the replacement area shall be avoided as far as possible. After chiseling, the reinforcement in the replacement area shall be straightened. If the retained reinforcement fails to meet the original design requirements, it shall be supplemented according to the original reinforcement requirements. If the reinforcement is damaged, it shall be replaced with the reinforcement of the same specification.

⑧ Grouting materials replacing

The non-shrinkage cement-based grouting materials with aggregate of class IV of C50 strength grade shall be used for the parts below the elevation of 14.450m (including); the non-shrinkage cement-based grouting materials with aggregate of class IV of C40 strength grade shall be used for the parts above the elevation of 14.450m. The replacement of local special-shaped shear wall and column shall be carried out in two times: the external part of the concrete shear wall component shall be removed first, accounting for 40% of the replacement part; the remaining 60% of the replacement part can be removed and the replacement of grouting material can be carried out after the strength of the grouting material of the replacement part reaches C30; the external parts of the concrete column component shall be removed first, accounting for 40% of the replacement part, and the replacement part can be carried out after the strength of the grouting material reaches C30 removal of the remaining 60% of the middle and replacement of grouting materials.

3.3 Strengthening shear wall with prestressed steel bar method

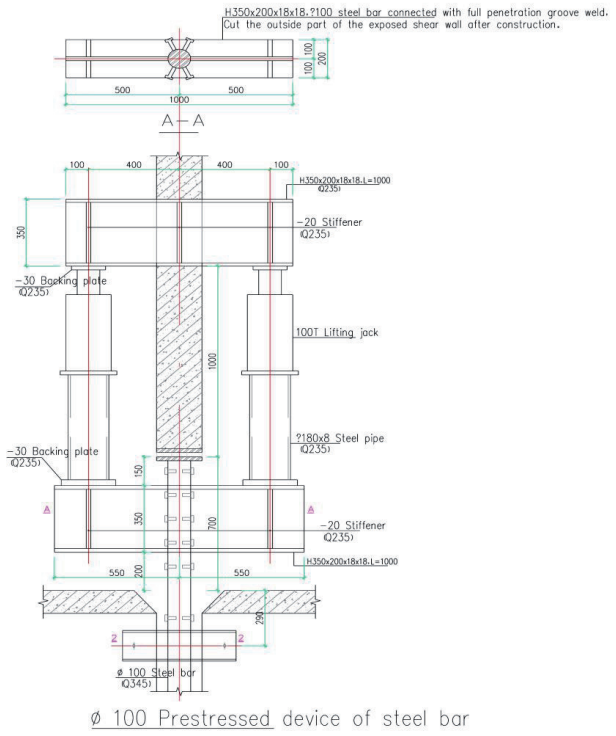

Fig.4 Principle of prestressed steel bar reinforcement method

Fig.5 Site diagram of prestressed steel bar reinforcement method

The concrete method of strengthening shear wall with prestressed steel bar method is as follows (Fig. 4): a vertical groove with a width of about 250mm is manually dug in the shear wall. The rough surface is naturally formed, and the wall reinforcement shall be kept as far as possible. The damaged part shall be welded with the same specification reinforcement after the steel bar is placed; when meeting the main reinforcement of the floor beam, the beam reinforcement shall be bent down 90 degrees for anchoring, and the beam bottom reinforcement shall be bent up 90 degrees for anchoring. Steel bar column with diameter Φ100 shall be placed in the vertical groove. There are

64mm Φ16 cylindrical head studs welded on the steel bar column. The cylindrical enlarged head is mainly used to prevent stress concentration, avoid cracks at the joint with concrete, and increase the occlusion between the bolt and concrete. The number of cylindrical head studs is calculated according to the pressure value it needs to transmit. H-shaped steel is set as reaction steel beam on the upper part of the channel body, and H-shaped steel welded vertically with the steel bar column is used as force transmitting steel beam. After the steel bar column is prestressed to the design requirements through the Φ180×8mm steel pipe and jack set between the reaction steel beam and the force transmitting steel beam, the upper and lower ends of the prestressed steel bar are anchored with the shear wall with epoxy resin concrete, and the steel bar and the channel body are knocked with steel wedge Part of the shear wall is tightened, and then the vertical slot in the shear wall is poured with non-shrinkage cement-based grouting material with coarse aggregate. During the construction process, channel steel is used as temporary lateral support to ensure the stability of the newly prestressed Φ100 steel bar column (Fig.5). After the construction, the stability of the prestressed Φ100 steel bar column is guaranteed by the shear wall. Finally, according to the structural requirements, the reinforcement method of reinforced concrete composite mortar is adopted to increase the reinforcement properly, so as to improve the ductility of the wall.

(1) Construction technology

Positioning and setting out → chiseling the surface of shear wall → setting up the installation slot of shear wall → installation of reaction frame steel beam and force transmission frame steel beam → installation and quality acceptance of steel bar and support system → partial replacement of steel bar bottom → embedded installation and monitoring system → prestressing the steel bar by stages → fixing the upper bearing end of the steel bar → unloading by stages → reinforcement restoration → formwork erection, grouting material pouring → formwork removal → maintenance → removal of reaction frame and fixed steel bar lateral support, cutting of force transmitting steel beam → binding, planting and welding of steel mesh on wall surface → spraying of high-performance composite mortar → maintenance.

(2) Technical points

① Setting out

According to the drawing requirements, the location and setting out of the embedded steel bars shall be carried out. Due to the large stress and many reinforcement at the edge components of the shear wall, the new prestressed steel bar column shall be arranged as far as possible to avoid the edge components of the shear wall. A 250mm wide wall through slot and a horizontal reaction steel beam through the hole of the top shear wall are set up by mechanical and manual chiseling. The

replacement construction shall be carried out first in case of the construction of embedded steel bars in the shear wall according to the design requirements, and the slotting construction shall not be carried out until the strength of the grouting material in the replacement part reaches the strength required by the temporary design and construction.

② Steel bars making

The shaped steel bars shall be made in the processing yard according to the requirements of the design drawings, and the temporary horizontal force transmitting steel beam part of the stud can be welded on site.

③ Supervising

Steel bars and force transmitting steel beams shall be erected in the groove. The steel bars and steel beams shall be connected by full penetration groove welds. The verticality of the steel bars shall be strictly checked and the flatness of the upper and lower base plates shall be checked (the gap between the base plate and the concrete contact surface shall be filled with modified epoxy slurry).

④ Jacking support system placing

The horizontal reaction steel beam and the auxiliary jacking support system shall be placed, which the upper flange of the reaction steel beam should place close to the upper part of the hole according to the requirements of the drawing, and the jack is used to support the lower part. The contact surface between the upper flange of the reaction steel beam and the concrete with epoxy slurry should be filled. The support steel pipe and Jack on the lower transmission steel beam should be set after the grouting material of the upper part of the steel beam reaches the specified strength, and the jack is used to add pressure to ensure that the structural adhesive density and the flatness of the upper and lower surfaces of the steel beam.

⑤ Data collecting

The prestressing force is applied to the steel bars in different grades according to the design requirements. The data of stress changes are collected, and the stress value is adjusted according to the data, so as to ensure the reliable and effective stress of the steel bars.

⑥ Anchoring

The upper and lower ends of the prestressed steel bars are anchored to the shear wall with epoxy resin concrete after the stress value is applied to meet the design requirements. After it is reliable, the gap between the steel bar and the upper base plate shall be firmly plug welded with a steel wedge, and the hydraulic jack and the jacking member can be removed after the level unloading.

⑦ Restoring

The reinforcement at the original structure of the channel mouth should be restore after the connection and welding of the reinforcement at the channel mouth is completed and the formwork is erected. Then the grouting material is used for pouring and compaction; after the grouting material reaches the strength, remove the reaction frame and fix the lateral support of the steel bar, and cut off the force transmitting steel beam.

⑧ Roughening

Chisel off the surface concrete of shear wall until the new surface of structure is exposed, and spray special interface agent.

⑨ After works

Steel mesh shall be bound on the wall surface, and high-performance composite mortar shall be sprayed after acceptance checking.

4. Construction monitoring

In the process of structural strengthening, the internal force of steel supporting structure, internal force of steel bar, wall stress and displacement of upper supporting wall of replacement layer are monitored to ensure the reliability and effectiveness of structural strengthening. The monitoring of the internal force of the steel support structure (Fig.6) and the steel bar is through the arrangement of reinforcement meters on both sides of the middle part of the support structure and the middle part of the stress surface of the steel bar. The monitoring of the wall stress is to embed a pair of surface strain gauges at the midpoint of the connecting line of the supporting structure on both sides of the tested wall. The displacement monitoring of the upper support wall of the replacement layer is to set the observation point of the static level at the middle point of the upper support wall of the replacement layer and the two support lines (Fig. 6) as the monitoring point of displacement measurement; the observation point of the static level is set on the wall not affected by the deformation as the reference point, so as to observe the relative deformation between the reference point and the monitoring point.

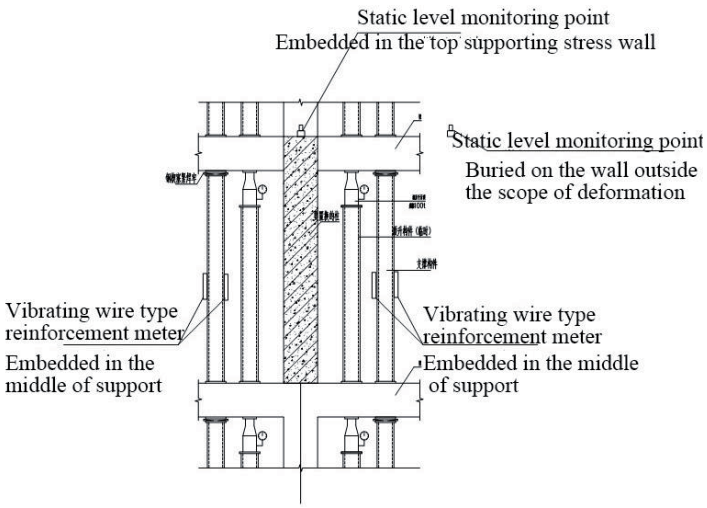

Fig.6 Schematic diagram of monitoring point layout

The monitoring data shows that: after the removal of the prestressed loading device, the measured values of the axial pressure of the steel bar are all greater than 85% before the removal, most of which are more than 90%, meeting the design requirements. Under different working conditions, the maximum vertical displacement of the replacement shear wall roof is 0.2mm, meeting the design requirements of not more than 0.3mm.

5. Conclusion

In the process of reinforcement, several reinforcement methods are combined and different reinforcement methods are adopted in different parts of the building: enlarging section method is adopted for two-story basement; after strict unloading and monitoring measures are taken for a small part of shear walls from one to six floors, the method of multiple replacement is adopted; for the rest of the above ground shear walls, the reinforcement method is adopted The first prestressed steel bar reinforcement method was adopted in China. Through the comprehensive application of these reinforcement methods, while ensuring the reinforcement effect, the characteristics and advantages of various methods are fully utilized, which not only ensures the reliability and economy, but also ensures the user's use area, shortens the construction period, and can be vigorously promoted and implemented in the development of similar projects. After the project reinforcement,

through the monitoring unit monitoring, the prestressed steel bar and shear wall deformation meet the design requirements, and the reinforcement project has passed the acceptance of experts.

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