Application of comprehensive method in strengthening of a tall building

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Abstract. The concrete strength is low, which has a great influence on the compressive bearing capacity, column axial pressure ratio and column reinforcement. In order to solve such problems, it is often strengthened by increasing the section method. However, the use of increasing section method significantly affects the clearance of the building. So, it is strengthened by comprehensive method, in order to not significantly affect the clearance, that is using the outsourcing steel method and the increasing section method simultaneously. This method combines the advantages of the two most commonly methods, the increasing section method and the outsourcing steel method. The bearing capacity of the strengthened member is greatly improved, which not only reduces the influence of the increasing section method on the clearance, but also reduces the area of the externally-formed steel required. Since the adhesive is not required when pasting the steel, the durability of the strengthened member is improved.

1. Introduction

When the strength of the component concrete is insufficient, the commonly used reinforcement methods are: increased section reinforcement method, replacement concrete reinforcement method, external prestress reinforcement method, externally bonded steel reinforcement method, bonded fiber reinforced composite material reinforcement method, and bonded steel plate reinforcement method. However, when the strength of the concrete of the component is seriously insufficient, the commonly used strengthening methods include: strengthening section strengthening method, external bonding steel strengthening method, etc. Increasing section reinforcement method, also known as outsourced concrete reinforcement method, has simple construction technology and wide application area, but it has a large amount of wet work on site and a long curing time. The increase of the section of the component will affect the appearance of the structure and the house clearance [1]. Externally bonded steel reinforcement method is a method of enclosing the steel around the component. The construction period is short and the cross-section size of the component does not increase much. However, the positioning and thickness of the joints are strictly required, and protection is required. This paper introduces a reinforcement method that comprehensively increases the section reinforcement method and the externally bonded steel reinforcement method. The use and calculation of the method are discussed in detail through an example.

A high-rise comprehensive office building, part of the main building is 17 floors above ground, and the basement is now under construction to the 16th floor. During this period, it was found that the core-like strength of the two-layer 15/C, 16/C, 15/E, and 15/F column cores only reached 18.9 to 22.3 MPa, while the original design strength was C50. According to the site's understanding, this situation was caused by the commercial mixed company mixing a bottom-marked concrete into a
high-marked concrete convoy. In order to ensure timely and safe delivery, the owner requires the building to be reinforced.

2. Case analysis
The strength of the problem column concrete varies greatly, which has a greater impact on the compressive bearing capacity, column axial compression ratio, and column reinforcement. In order to solve this kind of problem, the general length is reinforced by the method of increasing section. However, the increased section method has a greater impact on the original building space, and the owner has higher space requirements. Another commonly used reinforcement method is externally bonded steel, but after rough estimation of the bearing capacity under pressure, the area of the externally bonded steel is too large, which adversely affects the construction of the paste. Through analysis and comparison, considering the advantages and disadvantages of these two commonly used reinforcement methods, the author proposes a comprehensive method for reinforcement, that is, the reinforcement method of comprehensively increasing the section reinforcement method and the externally bonded steel reinforcement method. This method not only reduces the impact of the increased section method on the clearance, but also reduces the area of the required externally-shaped steel. Adhesive is not required during the comprehensive method construction, which improves the durability of the reinforced members.

Both the outer-clad steel method and the increased section method increase the stiffness of the original column, which causes the redistribution of the internal force of the original structure. Therefore, the increased stiffness needs to be substituted into the original structure for calculation. Initially estimate the increased cross-sectional area and the area of the externally bonded steel, and then use the equivalent stiffness conversion section to substitute the original structure for calculation. Compare the calculated reinforcement of the beam and column with the actual reinforcement of the original beams and columns. If there is a positive difference, they need to be reinforced, and then check the bearing capacity of the reinforced members. Repeat the above steps until the requirements are met.

3. Calculation process

3.1 Preliminary Estimates of Increasing Sections and Outer Angle Angles
Taking 15 / C column as an example, it is planned to use a surrounding 110mm envelope for the enlarged section. The concrete in the envelope is configured with 12 longitudinal steel bars with a diameter of 22, and the steel bars should avoid the beams as much as possible to maintain the upper and lower communication. Considering the strain lag, the strength utilization coefficient of the newly added concrete and steel bar is taken as 0.8. Initially estimate the area of the outer angle steel through the axial pressure ratio limit (Eq. 1). The axial force is selected according to the control axial force for calculating the axial pressure ratio of the original column. The actual concrete strength design value is calculated as 9.02 Mpa (= 0.76 × 0.88 / 1.4), and the strength utilization factor of the newly added steel is taken as 0.9. The required angle steel area is calculated according to Equation 2.

\[
\begin{align*}
\frac{u}{2} & = \frac{N}{f_{co}A_{co} + 0.8f_{c}A_{c} + 0.9f_{c}A_{a}} \leq u_{c} = 0.80 \\
A_{a} & = \mu \frac{N - f_{co}A_{co} - 0.8f_{c}A_{c}}{0.9f_{a}}
\end{align*}
\]
3.2 Calculation of member stiffness after preliminary estimation

After the section is proposed to be enlarged, the elastic modulus and concrete strength of the composite section are calculated by the weighted average method. The stiffness of the section after increasing the section is calculated according to Equation 3.

\[ E_i l_i = E \frac{bh^3}{12} \]

The rigidity of the back section of the coated steel is calculated according to Equation 4.

\[ EI = EI_i + 0.5 E_a A_a a_a^2 \]

The equivalent stiffness section size (according to the square) is calculated according to Equation 5.

\[ b = \sqrt{\frac{12EI}{E}} \]

The weighted concrete strength of the composite section is calculated according to Equation 6\[1\].

\[ f_{cc} = f_{ccw} A_{ccw} + 0.8 f_{c} A_{c} \]

The column is modified to a column with side length b and the concrete compressive design strength \( f_{cc} \) is substituted into PKPM for calculation.

3.3 Comparison of reinforcement before and after strengthening

Calculate the structure after the equivalent stiffness column is substituted, consult the PKPM to calculate the reinforcement file, and compare the reinforcement area of the members before and after the reinforcement. If the calculated reinforced area after the proposed reinforcement is smaller than the originally calculated reinforced area, the component meets the bearing capacity requirements; otherwise, the calculated reinforced area after the proposed reinforcement is compared with the actual reinforced area. If the calculated reinforcement area is smaller than the actual reinforcement area after the proposed reinforcement, the component meets the bearing capacity requirements; otherwise, the component needs to be reinforced.

3.4 Check calculation of column cross section bearing capacity

From the calculation results of the PKPM after pseudo-reinforcement, the control bending moment and axial force of the reinforcement are calculated for calculation. Calculate the area of the angle steel to be configured according to the following formula \[2\]. Considering the strain lag, the strength utilization factor of the newly added steel is 0.7, and the strength utilization factor of the new concrete and steel bar is 0.8. Compare the preliminary estimated angle steel area with the calculated angle steel area. If the preliminary estimated angle steel area is greater than the calculated angle steel area, strengthen it according to the preliminary estimated angle steel area; otherwise, increase the angle steel area, and then calculate from Article 3.3 and repeat Until the bearing capacity requirements are met.

\[ N \leq \alpha_i f_{cw} bx + f_{yw} A_{yw} - \sigma_{yw} A_{yw} + a_u f_a - a_u \sigma_u A_u \]

\[ Ne \leq \alpha f_{cw} bx \left( h - \frac{x}{2} \right) + f_{yw} A_{yw} \left( h - a_{yw} \right) + \sigma_{yw} A_{yw} \left( a_m - a_u \right) + a_u f_a A_u \left( h - a_u \right) \]

3.5 Check calculation of inclined section bearing capacity

Calculate the control shear force of the reinforcement from the PKPM calculation results after pseudo-reinforcement, and calculate the shear bearing capacity of the inclined section of the component according to Equation 9 \[3\]. Considering the strain lag, the concrete strength utilization factor is 0.7 and the stirrup strength utilization factor Take 0.9. If the bearing capacity of the oblique section of the component meets the requirements, it should be reinforced according to the preliminary estimation of
the angle steel area; otherwise, the angle steel area should be increased. Similarly, the calculation is started from Article 3.3 of this article and repeated until the bearing capacity requirements are met.

\[ V \leq \frac{1.75}{0.1 + 1} f_{ve} h_b + f_{ye} \frac{A_v}{s} h_b + 0.07 N + 0.7 f_{ye} \left( \frac{A_v}{s} \right) h \]  \hspace{1cm} (9)

3.6 Axial pressure ratio and check calculation of node core area

The axial pressure ratio is an important indicator for controlling the ductility of the column. After reinforcement, it should be checked whether the column axial pressure ratio is controlled within the allowable axial pressure ratio. Check the calculation according to formula 1. In reinforced concrete frames, in addition to ensuring sufficient bearing capacity and deformation capacity of beam and column members, it is also very important to ensure the shear capacity of the joints. The important measure is to ensure the strength and compactness of the concrete in the joint area and the joint strength at the joints. With sufficient stirrups in the core \[ [4] \], it is necessary to check the bearing capacity of the core area of the node.

The seismic shear capacity of the cross section of the joint core area is checked and calculated according to the following formula.

\[ V_j \leq \frac{1}{\gamma_{RE}} \left[ 1.1 \eta_j f_{ve} h_j + 0.05 \eta_j N_j b_j + f_{ye} A_{em} \frac{h_{max} - a_j}{s} \right] \]  \hspace{1cm} (10)

The design value of the shear force in the core area of the joint is verified by the following formula.

\[ V_j \leq \frac{1}{\gamma_{RE}} \left( 0.30 \eta_j f_{ve} h_j \right) \]  \hspace{1cm} (11)

4. Strengthening design

The comprehensive method is a combination of the enlarged section method and the externally bonded steel. The most basic steps are: firstly tying up the new steel reinforcement, then positioning the externally bonded steel, and finally pouring the concrete. It should be noted that measures should be taken to ensure the co-action between new and old concrete and externally bonded steel, such as: chiseling the old concrete surface, and brushing the cross-section agent after cleaning. Shear bars are inserted between the new and old concrete to ensure force transmission. On the other hand, the anchoring of the upper and lower ends of the reinforced column is also the key point. The newly-added steel bars and externally bonded sections should pass through the floor slab, and keep the upper and lower through. The middle must not be disconnected \[ [5] [6] \]. The anchoring position of the lower end is determined according to the basement roof. If the basement roof can be used as the embedded end, the lower end is anchored to the basement roof, otherwise it should be anchored to the foundation \[ [7] \]. The upper end is anchored on the top plate of the reinforced column, and the anchorage length of the steel bar should meet the requirements.

5. Conclusion

1. The comprehensive method combines the advantages of the two most commonly used strengthening methods of the enlarged section method and the externally bonded steel method, which greatly improves the bearing capacity of the reinforced members. It not only reduces the impact of the increased section method on the clearance, but also reduces The required area of the externally bonded steel is small. Since an adhesive is not required when attaching the profiled steel, the durability of the reinforcing member is improved.

2. After the comprehensive method is strengthened, the rigidity of the original component is increased, which causes the internal force redistribution of the original structure. The influence on the remaining components should be considered in the calculation. The calculation uses the equivalent stiffness test algorithm.

3. Reinforcement design should emphasize two aspects. On the one hand, measures should be taken to ensure the common stress of the new and old parts, and on the other hand, anchorage at the upper and lower ends should be ensured.
4. During the reinforcement construction, care must be taken not to cause major damage to the original structure, the positioning of the outer sticky steel should be accurate, and the surface of the steel members should be treated with fire prevention and corrosion protection. Reinforcement construction must be completed by a professional company with special qualifications.

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