SECTION OPTIMIZATION OF FRAME-CORE TUBE STRUCTURES BASED ON THE EFFECTIVE PROCESSING OF CONSTRAINT RELATIONS

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Abstract

The core tube structure of the super-high-rise frame has always had a wide variety of optimization constraints owing to its complex structure, the lack of the principle of effective constraint selection and the unclear relationship between constraints. This paper pays attention to the study of the selection of optimization constraints and their relationship in the optimization process, as well as the optimal selection of optimization targets, to study the cross-sectional optimization of the core tube of the super-high-rise frame. The reason why we constructed these three screening principles was that by classifying and integrating the provision constraints in the specification (such as rigid-weight ratio of structure, shear-weight ratio, inter-story drift, etc.) stipulated in the code, it is proved that these constraints have an impact on the performance of the structure, and six representative constraints (cycle ratio of structure, rigid weight ratio, shear weight ratio, inter-layer displacement angle, etc.) are established to demonstrate the strength and weakness of these constraints. On this basis, the rigidity equivalent relationship of structurally related components (such as frame columns, beams, extended outrigger trusses, and core tubes) is established by simplifying the calculation model, and the relationship between the rigid weight ratio of the structure and the inter-story drift is established. The entire process of cross-section optimization of the frame-core tube structure is realized by writing the MATLAB program. Through this process, the determination of the relevant stiffness parameters of the initial design of the structure can be achieved, so that we can obtain an initial good initial design, which is conducive to the structural designer initially determine the shape and size of the cross-section, therefore the structure of the design meets the requirements of the specification, on this basis, the optimization of the cross-section can be achieved through iteration, and then a better design can be obtained. The optimization process proposed in this paper realizes the applicability of the optimization of the core tube of the super-high-rise frame, and finally makes an example simulation of the core tube structure of the super-high-rise frame designd by myself, and the advantages of the proposed algorithm are confirmed by the data.

Keywords: optimization constraints; cross-section optimization; frame-core tube structure; constraint relations; optimization process

1 Introduction

In recent years, economic development and demographic trends have created an urgent demand for high-rise buildings, with a strong growth in the number of high-rise buildings[1]. In an abundant number of high-rise structural systems, the largest proportion of the structural system is the frame core tube structure with outrigger[2-3].The number of such structural members is large, the material consumption is large, and the cost is high. The optimization problem has always attracted the attention of research institutions and researchers[4]. The objectives of optimization range from simple and intuitive economics, material consumption to structural rigidity,etc. However, little attention is paid to the optimization constraints There is little research on the selection of constraints and the relationship between constraints. In the process of structural optimization, it is necessary to consider the design specifications[5-7] that the structural design must meet, but there are hundreds of rules in each codes. For different optimization problems, the effectiveness of each constraint is different. The loose constraint in problem A may become the tight constraint in problem B. In addition, the constraints in the same optimization problem are not necessarily completely independent each other. With slight changes in the optimization variables, there may be multiple constraints from the original state that meets the doesn't limit to the state that meet the limit. This will be reflected intuitively on the corresponding constraint indicators, and the relationship between these constraints is the focus of this paper. Therefore, this paper proposes a new method for cross-section optimization based on the effective processing of constraint relationships.

2 Simplification of computing models and related assumptions

Many high-rise buildings are willing to adopt relatively regular and symmetrical plane layout, and this kind of complex structure is particularly significant for the core tube structure of the super high-rise frame. Therefore, this paper focuses on the calculation and analysis of the ideal symmetrical structure.

2.1 Simplifications and assumptions

(1) The structure is in a state of elastic operation.

(2) The stiffness value of all floor beams, frame columns and outrigger trusses on one side of the frame structure is weighted by height along the vertical direction.

(3) Tube and exterior columns deform together. Due to the constraints of the rigid chain rod of the building, the horizontal load has the same side shift horizontal deformation and corner deformation under the action.

(4) The bending deformation and shear deformation of the tube is included, the axial deformation of the tube is ignored, and the horizontal section of the tube is assumed to remain at the level when the tube has shear deformation.

(5) The bending and shear deformation of the girder are included, the axial deformation is ignored, and the contra-flexure point of the girder is assumed to be in the cross.

(6) Axial deformation, bending deformation and shear deformation of the corner column are included.

(7) When the ratio of the line rigidity of the corner column EJ_z/h (h-height) to the line rigidity of the girder EJ_L/L is less than or equal to 2, the local bending deformation of the column will be greater, and the contra-flexure point of the girder will move closer to the column. At this time, the bending rigidity of the girder can be multiplied by 0.85 to reduce it, so as to reflect the influence of the local bending vibration deformation of the corner column.

2.2 Equivalent relationship of structural members

Regular and symmetrical high-rise buildings with uniform story mass and stiffness can be equivalent to continuum[8]. In this paper, the whole spatial structure is calculated by the height weighted average of structural members along the vertical direction.

(1) Equivalent relationship of Corner columns, girder and interior core tube

The weighted average formula of the stiffness of structural members is shown in Table 1:

Tab 1 – Equivalent relationship of the rigidity of structural members [9]

Corner columns	**Girder**	**Interior core tube**
$\mathrm{EI_z} = \dfrac{\sum_i \mathrm{E}_{zi}\mathrm{I}_{zi}\mathrm{h}_i}{\sum_i \mathrm{h}_i}$	$\mathrm{EI_L} = \dfrac{\sum_i \mathrm{I}_{Li}\mathrm{I}_{Li}\mathrm{h}_i}{\sum_i \mathrm{h}_i}$	$\mathrm{EI}_C = \dfrac{\sum_i E_{Ci}\mathrm{I}_{Ci}\mathrm{h}_i}{\sum_i \mathrm{h}_i}$
$\mathrm{GA_z} = \dfrac{\sum_i G_{zi}\mathrm{A}_{zi}\mathrm{h}_i}{\sum_i \mathrm{h}_i}$	$\mathrm{GA_L} = \dfrac{\sum_i \mathrm{G}_{Li}\mathrm{A}_{Li}\mathrm{h}_i}{\sum_i \mathrm{h}_i}$	$\mathrm{GA_C} = \dfrac{\sum_i G_{Ci}\mathrm{A}_{Ci}\mathrm{h}_i}{\sum_i \mathrm{h}_i}$
$\mathrm{EA_z} = \dfrac{\sum_i \mathrm{A}_{zi}\mathrm{A}_{zi}\mathrm{h}_i}{\sum_i \mathrm{h}_i}$	$\mathrm{EJ_L} = \dfrac{\mathrm{EI_L}}{1+\dfrac{12\mu \mathrm{EI_L}}{\mathrm{GA_L L^2}}}$	$\mathrm{I}_{Ci} = \dfrac{0.9}{12}\left[\left(C+\mathrm{t}_i\right)^4 - \left(C-\mathrm{t}_i\right)^4\right]$

Where: E_{zi}, E_{Li} and E_{Ci} is the elasticity modulus of concrete of the ith-story column, girder and core tude resepctively; h_i is the ith-story-height; G_{zi}, G_{Li} and G_{Ci} is the shear elasticity modulus of concrete of the ith-story column, girder,and core tude resepctively; A_{zi}, A_{Li} and A_{Ci} is the cross-sectional area of all corner columns, girders and core tude on one side of the structure of the i-th story resepctively; I_{zi}, I_{Li} and I_{Ci} is the total moment of inertia of the cross-section of all the corner columns, girders and core tude on the side of the structure of the i-th story; h_i is the height of the i-th story; μ is the non-uniformity coefficient of the shear strain of the coupling beam section, for the rectangular section: μ =1.2; C is the span of the core tube; t_i is the thickness of the core tube of the i-th story; L is the column space; B is the total structural width.

(2) Equivalent relationship of outrigger stiffness

$$\mathrm{EI_t} = \frac{m\gamma \mathrm{EA_r h^2}}{2} \; [10] \tag{1}$$

$$\gamma = \frac{\rho^2}{\rho^2 - 1} \; [10] \tag{2}$$

$$\mathrm{GA_t} = m\rho \frac{2\mathrm{a^2 h}}{\mathrm{d^3}} \mathrm{EA_d} \; [11] \tag{3}$$

Where: m is the number of outrigger trusses connected to the corner column on the side of the core tube and the core tube; γ is an augmentation factor, mainly consider the stiffening effect on the truss resulting from the axial force in the chords, which cannot vary linearly along the length of the outrigger.; ρ is the number of segments of the outriggers; A_r is the cross-sectional area of the top and bottom chords of the outrigger,; h is the height of the outrigger story; a is the length of the horizontal chord in the outrigger truss;d is the length of the inclined support in the outrigger truss; A_d is the cross-sectional area of the diagonal support in the outrigger truss.This phenomenon has been proved by Hoenderkamp and Snijder (2003b).

2.3 Simplified calculation model diagram

As shown in Figure 1, due to the symmetry of the structure, the effect of structural torsion can be ignored, and only one main axis direction can be taken for calculation. Combined with the above simplified principle and equivalent relationship, the entire spatial structure is merged into a plane structure, as shown in Figure 2 for solution[9].

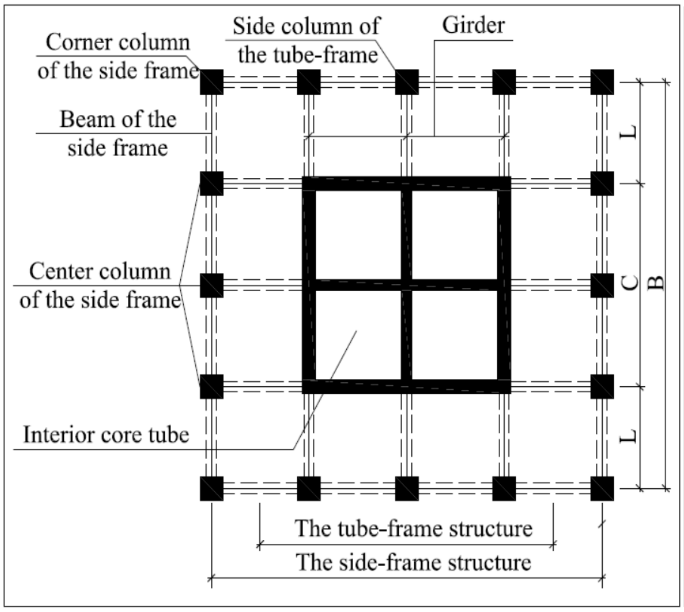

Fig.1 – structural plan

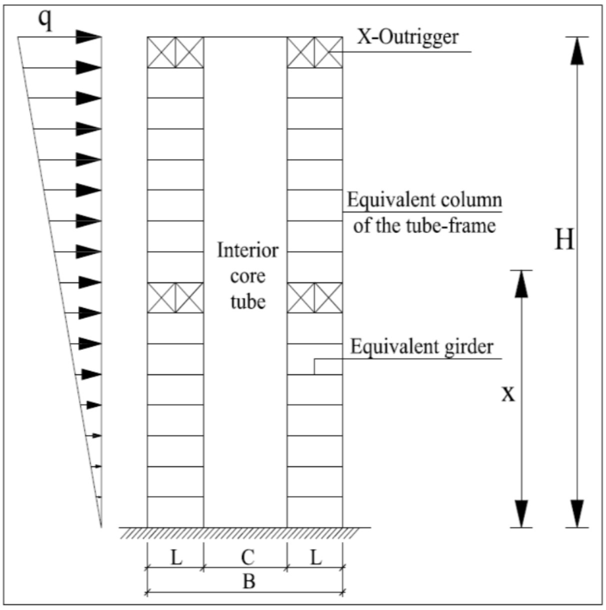

Fig.2 – Equivalent structure calculation diagram

3 Selecting Principles and Classification of Optimization Constraints

3.1 Selecting Principles of Optimization Constraints

The selecting principle in this paper is mainly to consider the correlation between the constraint and the structural section size or structural stiffness. Since entering the stage of section design and optimization, the overall structural parameters, such as the plane dimensions and height of the structure, have been basically determined. What is uncertain is the specific size and cross-sectional form of each component. Changes in these parameters will not change the overall shape of the structure. When the parameters change within a reasonable range, the structural stiffness will change, which will be related to the constraints related to the size of the structural section. At this stage, it is necessary to find out those constraints that are easy to exceed the specification limit when the size of the structural cross-sections change.

3.2 Optimization constraint classification

According to the selecting principle, the constraints are divided into three types: constraints based on cross-sectional dimensions, constraints based on structural stiffness, and constraints on other structural performance constraints.

Constraints based on cross-sectional dimensions are the geometric size limitation of the whole structure and the structural members, which are mainly reflected in the relevant limits of the component size. It mainly includes the aspect ratio of the core tube, the distance between the core tube and the outer frame column, the minimum width of the frame beam, the minimum side length of the frame column, the minimum thickness of the core tube and the floor, and so on.

Constraints based on structural stiffness are constraints or limits that are closely related to the calculation of structural stiffness. They mainly include the inter-story drift, the structural rigid-weight ratio, and the structural shear-weight ratio, etc

Other structural performance constraints are added to the structural state variables, such as structural vibration periods, and allowable values of component stresses. Generally, these constraints have implicitly depended on the design variables ,which are mainly used as the cycle conditions for optimization iteration in this paper.

For the frame core tube structure with bidirectional symmetry used in this paper, the structural torsional effect is not obvious, so the influence of the periodic ratio on the structural performance can be ignored. The control of the axial compression ratio and the shear compression ratio are important measures to ensure the ductility and safety of structural members. The axial compression ratio is generally used for the initial design of the cross-section during the initial design stage of the structure, and the shear compression ratio of the component is essentially the minimum area to control the cross-section of the component. In the optimization phase, these two are not the main constraints.

The shear-weight ratio of the structure is the ratio of the earthquake action to the representative value of gravity load. It is mainly considered that when the long-period structure is calculated by the mode decomposition response spectrum method and the bottom shear method, because the value of the seismic influence coefficient may be low, the corresponding calculated seismic action is also low. So for the structural safety, the minimum value of the horizontal seismic shear of the floor is specified in the code. The assumed inverted triangle load is adopted in this design, so it can be ignored temporarily. The inter-story drift reflects the ability of the high-rise building structure to resist lateral movement under the horizontal loads. It can prevent the structure from too small rigidity, resulting in large lateral displacement, even greater p-δ effect, which ultimately results in the structural instability damage.

The rigid-weight ratio of the structure reflects the overall stability of the structure under the horizontal loads. With the increase of the height and height-width ratio of the high-rise building, as well as the increase of the internal space of the building, the structural weight increases while the stiffness decreases relatively, and the problem of stability gradually became apparent.

Since the stiffness of the structure is closely related to the cross-sectional dimensions of the structural members, and the design of this paper is based on the equivalent treatment of the stiffness of the structural members, so it is reasonable to select two constraints, namely, the inter-story drift and rigid-weight ratio, which are directly related to the rigidity of the structure, to study.

4 Section optimization process and example analysis

4.1 Section optimization process

Based on the simplified calculation model and the related equivalent stiffness relationship, and considering that the height-width ratio of the frame core-tube structure is relatively large, the effect of shear deformation of the inner core-tube can be ignored. Therefore, the displacement at any position of the simplified model can be obtained as:

$$u(\zeta)=\frac{11\mathrm{V_0H^3}}{60\mathrm{EI}}\left\{\frac{20}{11}\zeta^2-\frac{10}{11}\zeta^3+\frac{1}{11}\zeta^5-\frac{60}{11}T\left\{\frac{1}{3}\zeta^2-\frac{1}{6}\zeta^3+\frac{1}{\alpha^2}\left\{\frac{1}{3}\zeta^3+\left(1-\frac{2}{\alpha^2}\right)\left(\frac{\mathrm{sh}\alpha\zeta}{\alpha}-\zeta\right)-\left[2+\left(1-\frac{2}{\alpha^2}\right)\alpha\mathrm{sh}\alpha\right]\frac{(\mathrm{sh}\alpha\zeta-1)}{\alpha^2\mathrm{ch}\alpha}\right\}\right\}\right\} \quad (4)$$

T and α will be at the optimum spacing under the situation when the dimensions of the cylinder, the cross-section of the column and column of the frame, and the cross-section of the roof beam are determined reasonably. Taking advantage of the coordinated space work of the tube frame structure, it can be concluded that the optimal interval of T and α is: T=0.6-0.85, α =1.5-2.5.

(1) Calculating the representative value of structural gravity load:

The average mass of the tube frame structure is 1300-1500kg/m^2, The value in this design is 1500kg/m^2

$$\mathrm{G}=\sum_{i=1}^{n}\mathrm{G}_i=\frac{1.5\mathrm{B}^2\mathrm{H}}{\mathrm{h}}\mathrm{g} \quad (5)$$

(2) In accordance with the calculation formula of the rigid weight ratio

$$\mathrm{EJ_d}\geq 2.7\mathrm{H}^2\sum_{i=1}^{n}\mathrm{G}_i\ ^{[6]} \quad (6)$$

assuming that the rigid-weight ratio is R, we can get

$$\mathrm{EJ_d}=\mathrm{RH}^2\sum_{i=1}^{n}\mathrm{G}_i=\frac{1.5\mathrm{B}^2\mathrm{H}}{\mathrm{h}}\mathrm{gRH}^2 \quad (7)$$

(3) Calculating the natural vibration period of the structure:

Supposed structure top displacement:

$$\Delta_T = \frac{m_0 g H^4}{8EJ_d} = \frac{G}{gH} \times \frac{gH^4}{8EJ_d} = \frac{GH^3}{8EJ_d} \tag{8}$$

The natural vibration period of the structure:

$$T_1 = 1.7\sqrt{\Delta_T} = 1.7\sqrt{\frac{H}{8R}} \tag{9}$$

(4) Load calculation:

From the response spectrum[6], the horizontal earthquake influence coefficients in the two main axis directions can be obtained:

$$\alpha_0 = \left[\eta_2 0.2^{0.9} - \eta_1\left(T_1 - 5T_g\right)\right]\alpha_{max} \tag{10}$$

or

$$\alpha_0 = \left(\frac{T_g}{T_1}\right)^{\gamma} \eta_2 \alpha_{max} \tag{11}$$

The standard values of base shear forces for horizontal earthquakes in the two main axis directions are:

$$V_0 = \alpha_0 G_{eq} = 0.85\alpha_0 G \tag{12}$$

Therefore, the maximum inverted triangle load that the structure can bear is:

$$q_0 = \frac{2V_0}{H} \tag{13}$$

(5) Calculating the inter-story drift of the structure:

Obviously, From formula (13), the magnitude of the displacement between stories is affected by the lateral stiffness of the structure. The relationship between the two constraints can be explored, due to the lateral stiffness of the structure, which can produce an effect on the rigid-weight ratio and the inter-story drift. So, we can find out that the derivative of displacement with height is ISD(inter-story drift) at any position, as follows:

$$\text{ISD} = \frac{du(x)}{dx} = \frac{11V_0H^2}{60EI}\left\{\frac{40}{11}\zeta - \frac{30}{11}\zeta^2 + \frac{5}{11}\zeta^4 - \frac{60}{11}T\left\{\frac{2}{3}\zeta - \frac{1}{2}\zeta^2 + \frac{1}{\alpha^2}\left\{\zeta^2 + \left(1 - \frac{2}{\alpha^2}\right)(\text{ch}\alpha\zeta - 1) - \left[2 + \left(1 - \frac{2}{\alpha^2}\right)\alpha\text{sh}\alpha\right]\frac{\text{sh}\alpha\zeta}{\alpha^2\text{ch}\alpha}\right\}\right\}\right\} \tag{14}$$

In this formula:

$$EI = \lambda EJ_d \ ^{[9]} \tag{15}$$

$$\lambda = \left[1 - \left(\frac{10}{11} - \psi_\alpha\right)T\right]^{[9]} \tag{16}$$

$$\psi_\alpha = \frac{60}{11} \cdot \frac{1}{\alpha^2}\left(\frac{2}{3} + \frac{2\text{th}\alpha}{\alpha^3} - \frac{\text{th}\alpha}{\alpha} - \frac{2}{\alpha^2\text{ch}\alpha}\right)^{[9]} \tag{17}$$

Therefore, the relationship between the inter-story drift and the rigid weight ratio is:

$$\text{ISD} = \frac{du(x)}{dx} = \frac{0.16\alpha}{\lambda R}\left\{\frac{40}{11}\zeta - \frac{30}{11}\zeta^2 + \frac{5}{11}\zeta^4 - \frac{60}{11}T\left\{\frac{2}{3}\zeta - \frac{1}{2}\zeta^2 + \frac{1}{\alpha^2}\left\{\zeta^2 + \left(1 - \frac{2}{\alpha^2}\right)(\text{ch}\alpha\zeta - 1) - \left[2 + \left(1 - \frac{2}{\alpha^2}\right)\alpha\text{sh}\alpha\right]\frac{\text{sh}\alpha\zeta}{\alpha^2\text{ch}\alpha}\right\}\right\}\right\} \tag{18}$$

(6) Conforming to the limit value$(ISD)_{max} \leq (ISD)_{lim} = 13/8000$, the optimum target value- optimum rigid weight ratio R, overall rigidity coefficient of the structure α and Optimum influential coefficient of overall stiffness T- is obtained by programming in MATLAB.

(7) Determining and optimizing the section according to the target value:

Stiffness coefficient of Coupling beam: $D=\frac{6EJ_L B^2}{L^3}$ [9] (19)

The overall rigidity of the side frame of the tube frame: $EI_0 = \frac{EA_Z B^2}{2}$ [9] (20)

Overall stiffness coefficient of the tube frame structure: $\alpha^2=\alpha_1^2+\alpha_2^2=\frac{DH^2}{EI_0 h}+\frac{DH^2}{EIh}$ [9] (21)

Influence factor of overall rigidity of cylindrical frame side column: $T=\frac{\alpha_2^2}{\alpha^2}$ [9] (22)

(8) According to the above formula, an iterative formula for section optimization is established as follows:

$$EI_c=EI-2EI_z=\left(\frac{1}{T}-1\right)\frac{EA_Z B^2}{2}-2EI_z=\frac{0.9E}{12}\left[(C+t)^4-(C-t)^4\right] \tag{23}$$

(9) Calculating the representative value of structural gravity load with the new sectional dimension:

楼面静荷载 6.5 kN/m^2,活荷载 3.5 kN/m^2,屋面静荷载 6 kN/m^2,活荷载 0.5 kN/m^2,墙 4 kN/m^2,假设柱子为正方形，边长为 a($a=\sqrt{A_z}$)

$$G_n=(4\,W_C+4*m\,W_S+W_L+W_T)*50 \tag{24}$$

Where:

the representative value of structural gravity load with side column W_S:

$W_S=\{6.5*L/2*1/2+4*(h-0.8)*(10-)/L+0.4*(0.8-0.2)*25\}*L/2+\{6.5*L/2*1/2*1/2+4*(h-0.8)*(10-a)/L+0.4*(0.8-0.2)*25\}*L/2+A_z*25*h+3.5*L/2*1/2*L/2+3.5*L/2*1/2*1/2*L/2$

the representative value of structural gravity load with corner column W_C:

$W_C=\{6.5*L/2*1/2+4*(h-0.8)*(10-)/L+0.4*(0.8-0.2)*25\}*L/2*1/2+\{6.5*L/2*1/2*1/2+4*(h-0.8)*(10-a)/L*1/2+0.4*(0.8-0.2)*25\}*L/2+A_z*25*h+3.5*L/2*1/2*1/2*L/2*1/2$

the representative value of structural gravity load with girder and slab W_L:

$W_L=4m*\{6.5*L/2*1/2+4*(h-0.8)*(10-a)/L+0.4*(0.8-0.2)*25+3.5*L/2*1/2\}*L/2$

the representative value of structural gravity load with the core tube W_T:

$W_T=25*[(C+t)^2-(C-t)^2]$

4.2 Flowchart of section optimization

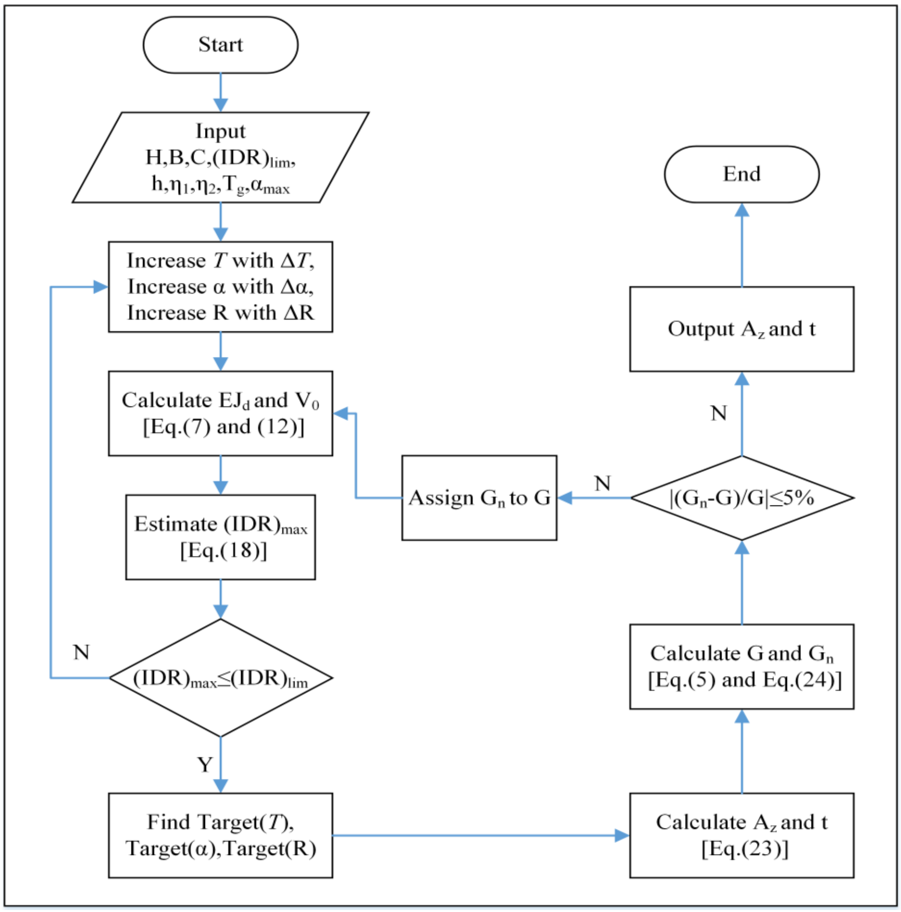

Fig.3 – Flowchart of section optimization

4.3 Example analysis

(1) Basic information

In order to better verify the effectiveness of the proposed process, a super high-rise frame-core tube structure with outrigger trusses with a height of 200m is designed in this paper. The structure strives for simple rules in the design. The finite element model is built in ETABS[12], in which all beams, columns and diagonal braces are simulated by the frame element, while shear walls and slabs are simulated by the shell element. The spectral acceleration is determined according to the Chinese design response spectrum[6] and its extension[13]. The maximum horizontal seismic influence coefficient is $\alpha_{\max} = 0.16$ and the characteristic period of the site, i.e. Tg, is 0.35s. The damping ratio ζ is equal to 0.03. The structural plan is shown in Figure 1, where the total plane width B is 40m, the core tube width C is 20m, and the column spacing L is 10m. In this design, the standard story height is 4m, the floor thickness is 200mm, and the reinforcement layer is located on the 25th and 50th floors. The frame column and the shear wall concrete strength grade in the structure is C50, the frame beam concrete grade is C45, the floor concrete grade is C40, and the outrigger truss is made of HRB400 steel bars. In this design, the cross section of all the main beams is 500*500mm, the cross section of the secondary beams is 300*500mm, and the thickness of the inner wall of the core tube is 200mm.

(2) Structural analysis results

Under this basic model, it can be obtained through the MATLAB program that the optimum structural rigid weight ratio R is 4.6, the optimum overall rigidity coefficient α is 2.5 and the optimum influential coefficient of overall stiffness T is 0.85.

Assuming that the structure is divided into four sections, the section of the column decreases by 100mm in sections and the section of the wall decreases by 50mm in sections. A program is written in Matlab by flowchart of section optimization, and the sections of the column and the shear wall are obtained as shown in Table 1:

Tab 1 – Section of structural components

Position	**Frame column side length (mm)**	**Core tube outer wall thickness (mm)**
1-12F	2300	500
13-25 F	2100	400
26-38 F	1900	300
39-50 F	1700	200

5 Conclusion

(1) In this paper, the relationship between the stiffness ratio of the structure and the inter story drift is obtained by simplifying the model and the equivalent stiffness relationship of the corresponding members. This proves that the rigid-weight ratio is roughly inversely related to the inter story drift. According to the structural mechanics knowledge, the greater the lateral stiffness of the floor, the smaller the displacement under the horizontal load. Therefore the inverse relationship between the rigid-weight ratio and the inter story drift is consistent with the theory.

(2) Through the section optimization process, the explicit relationships between the girder stiffness, core tube stiffness, overall column stiffness and column cross-section can be established directly and then the sections of each component that are more reasonable in the initial design stage can be obtained.This process does not require optimization algorithms and has high computing efficiency

(3) This paper does not ponder the correlations between the other constraints such as shear weight ratio and axial pressure ratio .In addition, only the rule of decreasing the cross-section of the column by 200mm in the vertical direction and decreasing by 100mm in the vertical direction of the shear wall is taken into account in this process.These will continue to explore in subsequent studies.

Appendix: Nomenclature

Symbol	**Definition**	**Unit**
E_{zi}	Elasticity modulus of concrete of the ith-story column	MPa
$E_{\mathrm{L}i}$	Elasticity modulus of concrete of the ith-story girder	MPa
$E_{\mathrm{C}i}$	Elasticity modulus of concrete of the ith-story core-tube	MPa
G_{zi}	Shear elasticity modulus of concrete of the ith-story column	MPa
$G_{\mathrm{L}i}$	Shear elasticity modulus of concrete of the ith-story girder	MPa
$G_{\mathrm{C}i}$	Shear elasticity modulus of concrete of the ith-story core-tube	MPa
I_{zi}	Total moment of inertia of the cross-section of all the corner columns on the side of the structure of the i-th story	mm^4
$I_{\mathrm{L}i}$	Total moment of inertia of the cross-section of all the girders on the side of the structure of the i-th story	mm^4
$I_{\mathrm{C}i}$	Total moment of inertia of the cross-section of all the core tube on the side of the structure of the i-th story	mm^4

A_{zi}	Cross-sectional area of all corner columns on one side of the structure of the i-th story	mm^2
A_{Li}	Cross-sectional area of all girders on one side of the structure of the i-th story	mm^2
A_{Ci}	Cross-sectional area of all core tude on one side of the structure of the i-th story	mm^2
h_i	Height of the i-th story	mm
μ	The non-uniformity coefficient of the shear strain of the coupling beam section	
t_i	Thickness of the core tube of the i-th story.	mm
H	Total structural height	mm
B	Total structural width	mm
C	Span of the core tube	mm
L	Column space	mm
m	The number of outrigger trusses connected to the corner column on the side of the core tube and the core tube	
γ	An augmentation factor	
ρ	The number of segments of the outriggers;	
h	Height of the outrigger story	mm
a	Length of the horizontal chord in the outrigger truss	mm
d	Length of the inclined support in the outrigger truss	mm
A_d	Cross-sectional area of the diagonal support in the outrigger truss	mm^2
A_r	Cross-sectional area of the top and bottom chords of the outrigger	mm^2
G	Representative value of structural gravity load	N
G_i	Representative value of structural gravity load of the i-th story	N
g	Acceleration of gravity	mm^2
EJ_d	Total lateral stiffness of the structure	$N \cdot m^2$
R	Rigid-weight ratio	
Δ_T	Supposed structure top displacement	mm
T_1	The natural vibration period of the structure	s
α_0	Horizontal seismic influence coefficients	
T_g	Characteristic period of the site	s
α_{max}	Maximum horizontal seismic influence coefficient	
V_0	The standard values of base shear forces for horizontal earthquakes	N
q_0	Maximum inverted triangle load	N/m
α	Overall stiffness coefficient of the tube frame structure	
T	Influence factor of overall rigidity of tube frame corner column	
ζ	Height variation coefficient	
A_z	Sectional area of column	mm^2

t	Thickness of the core tube.	mm
G_n	representative value of structural gravity load with the new sectional dimension	N
W_S	Representative value of structural gravity load with side column	N
W_C	Representative value of structural gravity load with corner column	N
W_L	Representative value of structural gravity load with girder and slab	N
W_T	Representative value of structural gravity load with the core tube	N

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