Optimal Design and Application of High-rise Building Structure Based on Hybrid Genetic Algorithm

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ABSTRACT

With the rapid growth of my country's economy, the continuous improvement of people's living standards, the gradual increase of the urbanization rate, the scope of urban land is becoming more and more tight. To solve this problem, urban architecture needs to be developed from low to high. In the design stage of high-rise buildings, there are often unreasonable layouts of many structural elements. Therefore, the scheme design and optimization in the design stage are more important. This paper aims to study the optimal design and application of high-rise building structure based on hybrid genetic algorithm. Based on the analysis of the structural design characteristics of high-rise buildings, the reinforced concrete structure system of high-rise buildings and the concept of genetic algorithm, taking a 15-story shear wall residential floor in a residential area as an example, the building structure is pure scissor wall structure, and the total building height is 40m. In this paper, the genetic algorithm and one-way search algorithm are combined to optimize the structure. The one-way search algorithm is used for local search, and the genetic algorithm is used for global search. The experimental results show that the optimized structure period is generally longer than the previous period.

Keywords: *Hybrid Genetic Algorithm, One-way Search Algorithm, High-rise Building, Structure Optimization*

1. INTRODUCTION

In recent years, with the rapid development of my country's economy and technology, the process of urbanization has continued to advance, and the number of high-rise buildings in various regions has increased rapidly [7]. Due to the pursuit of architectural design innovation and the special requirements for style and space conditions, more and more high-rise buildings have exceeded the height and type requirements applicable to relevant national regulations [1].

Structural optimization design has gone through three research stages: structural element and beam optimization, mathematical programming introduced mechanism optimization design, and finite element analysis combined with optimization design. With the enrichment of optimal design theory, researchers began to study the differentiation of structural design methods, from size optimization to shape optimization to the final topology optimization [4]. Nowadays, with the in-depth research of domestic and foreign designers, more and more structural optimization algorithms are applied to actual projects. Some researchers have applied intelligent algorithms to the topological optimization design of flat beams with logical results. Intelligent algorithms find the best solution in a given area [8]. Although this method is more stable, it also has the disadvantage of slower calculation speed. The most common advanced structure optimization algorithm is the optimal criterion (OC method for short). The OC method has the advantages of short time consumption and stable convergence of optimization results. For complex structures with different design variables and many constraints, they have been widely used in the research process of building structure optimization design [5]. Some designers use the OC method to optimize the air resistance structure design of various high-rise buildings. Some researchers have rigorously created the OC method. The OH method and the quadratic programming method based on the optimal Kuhn-Tucker condition are both used in the calculation of Lagrange multipliers. The application of structural optimization theories has attracted the attention of many

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experts and scholars. Various optimization theories have also been successfully applied in engineering practice, creating great value. Our country has made considerable progress in structural optimization design.

On the basis of consulting a large number of relevant references, this paper combines the characteristics of high-rise building structure design, high-rise building reinforced concrete structure system and the concept of genetic algorithm, combined with genetic algorithm and one-way search algorithm, to carry out a 15-story scissor-wall residential structure in a residential area.

2. OPTIMAL DESIGN AND APPLICATION OF HIGH-RISE BUILDING STRUCTURE BASED ON HYBRID GENETIC ALGORITHM

2.1. Features of High-rise Building Structure Design

2.1.1. Horizontal load effect

A characteristic of high-rise structures affected by horizontal force loads is that the arms are large, and the horizontal arms of low-rise buildings are small, so the threat to the structure is small, while high-rise buildings are just the opposite. When it comes to using the building's own weight and floor loading effects, ultimately all forces are transmitted to the vertical support members in a purely transmission manner. The representative value of the main factors affecting the axial force and the load. The gravity load is the main threat to the large-diameter structure. Under the action of horizontal force, the entire structure is like a cantilever beam and the relationship between the roll moment and the height It is a square, and the displacement structure at the top is related to the height of the fourth force [6].

2.1.2. Lateral displacement obviously affects the normal use of the structure

Different from low-rise and multi-storey buildings, under the influence of horizontal force, the displacement of the upper part of the high-rise building becomes more obvious, even beyond the range that can be withstood by normal use. The higher the height of the building, the closer the conceptual growth projection model is to reality, and its lateral displacement is related to the fourth power of the height. The higher the height, the faster the growth rate, and the lateral displacement control will definitely be more difficult.

2.1.3. Higher seismic design requirements

The main reason for the increased difficulty of earthquake planning is the height of the structure. Generally speaking, the higher the structure, the greater its flexibility, the longer the vibration period under earthquake action, and the more complex the dynamic characteristics of the structure. When an earthquake comes, the phenomenon of earthquakes will be more complicated [2]. In addition, the lower the level of the structure, the worse its uniformity, which makes the ductility design of the structure more difficult.

2.1.4. The structural self-respect further threatens the safety of the structure

For high-rise buildings, reducing structural weight is very important. Due to the multi-layer overlap, the foundation and the foundation are very difficult. Appropriate reduction of structural weight will significantly reduce foundation costs and foundation processing costs. The seismic force is an inertial force, and the heavier the structure, the greater the seismic effect. Under the action of horizontal seismic force, the increase of self-weight will increase the effect of shearing force, but at the same time, the more dangerous is the increase of overturning moment, which will significantly increase the total cost.

2.1.5. The axial deformation is more obvious

Under the factors of increasing gravity, obvious wind load, horizontal seismic force and other factors, the axial deformation of vertical members is more obvious, which puts forward higher requirements for structural strength. At the same time, it should be noted that for obvious axial deformation, there must be subsequent non-uniform axial deformation. The uneven deformation of the vertical element will cause more secondary stresses.

2.1.6. The influence of the concept on the structure is decisive

Due to the complexity of the structural effects of high-rise buildings, manual calculations are difficult, time-consuming and laborious, and the accuracy of the results cannot be guaranteed. The development of computer applications in structural design enables designers to perform more accurate and efficient calculations on more complex structures, all of which are based on the clarity of structural thinking. If a mistake is made in the conceptual design, all subsequent calculations will be useless, and wrong questions will definitely lead to wrong answers. Due to the limited number of people, designers need to have more conceptual understanding of structural design. Practice shows that the maturity of structural engineers depends on the understanding and application of structural concepts.

2.2. High-rise Building Reinforced Concrete Structure System

2.2.1. Frame structure system

According to the requirements of seismic design, the frame structure can be designed as a ductile frame with strong energy consumption and excellent seismic performance. The main disadvantage is that the lateral stiffness is relatively low. When used as a multi-storey building, large cross-section beams and columns must be used to ensure deformation requirements, reduce space usage and economic performance. In the seismic fortress area, the height of the frame structure must be lower than the prescribed limit. The frame structure is suitable for public buildings that require large space, such as shopping malls, exhibition halls, and light factory houses. The frame structure system has simple components and simple structure, and can generally be used in hotels, residences, office buildings and other buildings.

2.2.2. Scissor wall structure system

In the scissor wall system, the inner and outer walls of the building are made of reinforced concrete load-bearing walls, which can withstand horizontal forces. The cast load-bearing wall structure has the advantages of high integrity and high load-bearing. The lateral rigidity is high, the lateral deformation is small, and the seismic performance is good. The load-bearing wall of the seismic wall structure system also functions as a partition wall, and the sound insulation effect is good when a large formwork is used. The structure is simple and quick, and the inner wall is flat. However, due to the excessive number of scissors walls, the internal space is narrow, the structure itself is heavier, and the seismic effect is great. Therefore, the scissor wall construction system is suitable for buildings that require less space, such as houses, wards, and hotels [3].

2.2.3. Frame-scissors wall structure system

The frame-shear structure is to add a certain number of scissors walls to the frame of the beams and columns, and combine the frame with the wall scissors system, each has its own unique structure system. The frame-shear structure has the advantages of high spatial hierarchy, excellent ductility and lateral resistance, high rigidity and bearing capacity. At present, the frame shear system of high-rise buildings is the most widely used, mainly used in office buildings, public buildings and hotel buildings.

2.2.4. Frame-Simplified structure system

The frame-simplified structure is an ordinary frame, with a strong frame as the main lateral force component, with large column spacing around it, and its strength characteristics are similar to the frame-scissor wall structure. The building system is an ordinary floor plan, and its inner core tube can ensure that the structure has sufficient stability and thrust rigidity, seismic performance and mechanical properties are better than the frame-scissor wall structure.

2.2.5. Tube-in-tube structure system

The tube-in-tube structure system has excellent spatial integrity due to the short distance between the columns constituting the outer tube and the high rigidity of the beam. Unlike the standard horizontal frame, the tube-in-tube structure is like a porous vertical box girder, with excellent wind and seismic performance. The cylinder subjected to horizontal force is similar to the box-shaped cantilever member installed on the foundation, so it has higher thrust rigidity and load-bearing capacity, and has excellent torsional rigidity and space force performance. However, the tube-in-tube structure generally uses high-density, deep beams, which will reduce the ductility of the structure, and high-strength seismic zones require careful planning.

2.3. Basic Concepts of Genetic Algorithm

Genetic algorithm is an effective random search method based on the mechanism of natural selection and population genetics, and has a wide range of uses. Genetic algorithms find effective solutions to problems by artificially simulating natural selection and genetic mechanisms. At the beginning of the algorithm, starting from the first population, the natural law of survival of the fittest was adopted for individual selection, and subsequent genetic intervention created the next-generation population, which evolved from generation to generation until the expected conditions were met.

The genetic algorithm can be expressed as:

$$GA = (P(0), N, l, s, g, p, f, t) \qquad (1)$$

$$X = X_1, X_2, ..., X_n \qquad (2)$$

In the formula, N represents the number of individuals contained in the population; l is the length of the binary string; s represents the selection strategy; g represents the genetic operator.

3. EXPERIMENT

3.1. Project Overview

The calculation example in this paper is a 15-story scissor wall residential floor in a residential area in the city. Its structural form is a pure scissor wall structure, with a total building height of 40m and a total construction area of about 6,507 square meters. There are 18 floors above ground and 1 floor underground. The basement is 3.6m high, and the rest are 3m high. The height difference between indoor and outdoor is 300mm.

3.2. Hybrid Genetic Algorithm

3.2.1. Formation of the initial group

Part of the original population and others can be randomly generated through the actual structure and discrete variable sets, or using a one-way search algorithm. The strengths and weaknesses of the original team are critical to the development of the new team. Individuals have poor adaptability and are not easy to survive. If the adaptability to the entire group is not strong enough, more generations are needed to form better individuals for the next generation. In this way, part of the original population of the hybrid genetic algorithm needs to be formed through a one-way search algorithm. Because they are more adaptable, they can provide better characteristics for the entire group.

3.2.2. The evolution of the group

Throughout the evolutionary process, individuals in each generation of the population use the genetic functions of growth, mating and mutation to form offspring. In order to make full use of the fast local retrieval function of the one-way search algorithm, we can better manage the playback process and achieve a good work team. After the query is completed, the result code is loaded in the entire group, and the genetic algorithm is used to implement the global query.

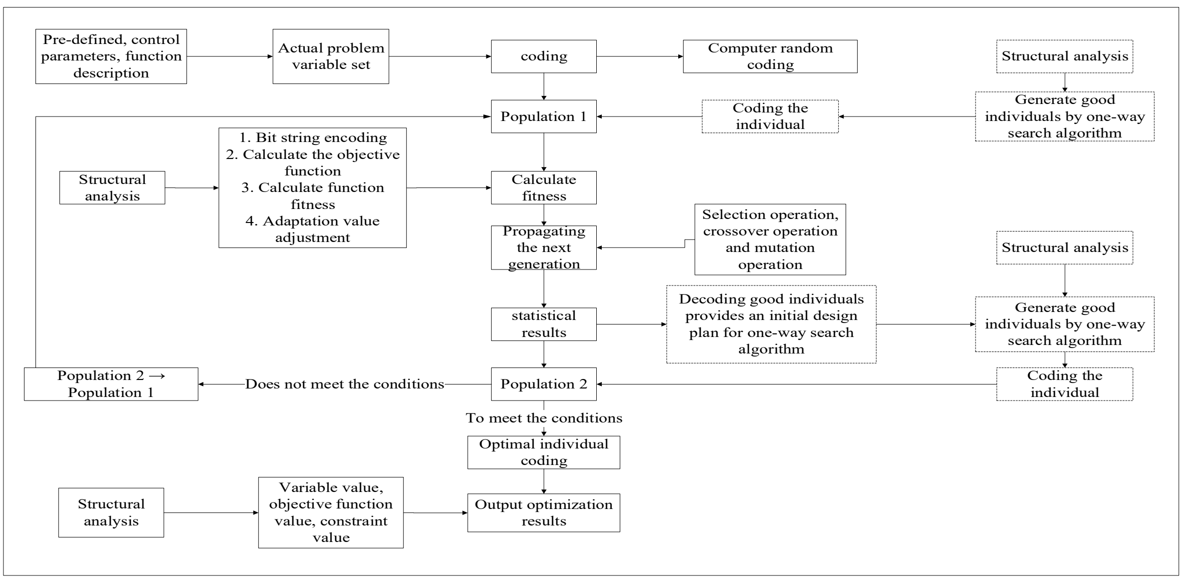

Figure 1. Flow chart of hybrid genetic algorithm

4. DISCUSSION

The vibration period of the structure can well reflect the distribution of the strength of the component in two directions. A rough judgment of the cycle can be used, and the structural components can also be adjusted appropriately. After calculating the SATWE finite element method and verifying the calculation, the analysis results are compared in Table 1 below.

Table 1. Vibration period comparison of different structural schemes

	Original model period value	Cycle value after optimization	Original model structure translation coefficient	Structural translation coefficient after optimization
1	1.2358	1.6366	0.94	1.00
2	1.2221	1.5862	0.90	1.00
3	1.0286	1.3943	0.12	0.00
4	0.3721	0.5048	0.90	0.98
5	0.3108	0.4402	0.98	1.00
6	0.2873	0.3976	0.10	0.01

7	0.1944	0.2669	0.92	0.98
8	0.1393	0.2095	0.65	0.99
9	0.1352	0.1926	0.40	0.01
10	0.1243	0.1708	0.93	0.97
11	0.0878	0.1260	0.94	0.98
12	0.0824	0.1203	0.38	0.97
13	0.0803	0.1158	0.65	0.01
14	0.0662	0.0904	0.95	0.97
15	0.0559	0.0850	0.32	0.98

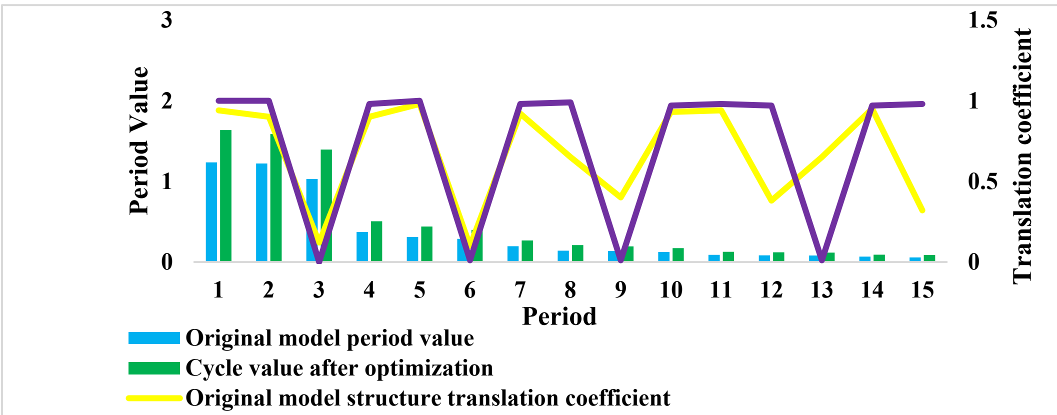

Figure 2. Vibration period comparison of different structural schemes

It can be seen from Table 1 and Figure 2 that the period before optimization is 0.0559-1.2358, and the period after optimization is 0.0850-1.6366. Under different formation conditions, the optimized structural period has generally increased compared with the previous period. Regarding the translational coefficient of the structure, since there are few cases of pure water movement in a single direction in the structure before the optimization, the torsion effect of the structure can be presumed to be more obvious, and all the structural vibration conditions of the optimized structure have been adjusted to pure Horizontal movement in the X direction or pure Y direction, so the torsion effect is weak.

5. CONCLUSIONS

People not only hope that the structure of the building is safe and reliable, but also meet the requirements of the function, economy and aesthetics of the building. Therefore, when designing structures, designers always seek a balance between structural safety, comfort and economy, and it has always been a difficult problem for designers to choose the best combination from many problems. Research shows that the optimal design of building structure reduces engineering costs, saves materials required for engineering, reduces environmental pollution, realizes the concept of low-carbon energy saving, and meets the needs of modern sustainable development.

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