Improvement of Adaptive GA Architectural Structure Optimization Design Model

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ABSTRACT: Classic genetic algorithm is not effective enough in building structural design optimization. This paper presents a building structure optimization design model based on improved adaptive genetic algorithm. First, taking characteristics of genetic algorithm into account, we improve its adaptive crossover probability and adaptive mutation probability so that the optimization process can be adaptive adjusted with the evolution of populations. We can use improved algorithms to do optimization for beams and columns of reinforced concrete frame structure. Simulation results show that using the improved genetic algorithm to optimize the design of building structure will significantly reduce the cost of project.
KEYWORD: Architecture Design; Reinforced Concrete; Adaptive Crossover; Adaptive Mutation; Structural Optimization

1 INTRODUCTION

Since the founding of New China, China has been carried out large-scale infrastructure construction. In order to ensure the rapid growth of the national economy, the real estate industry has been making great contribution as the pillar industry of the national economy. However, the overall level of the current design is still relatively low. When practitioners design beams and columns a lot of them tend to use larger cross-sectional dimension in order to guarantee the security of structure, which will blindly increase steel consumption. Due to the current drawing checking pay more attention to review whether it violates mandatory provisions of the regulatory requirements and seldom consider costs saving and reasonable designing. Thus, simply increasing the cross section and reinforcement ratio are taken as golden rules by some inexperienced designers, which will not only cause a huge waste, but also put little contribution to security. Therefore, to improve the design level and to optimize the design of the structure is necessary (Kwon Y D et al, 2003).

When Zhou Lang (Zhou Lang, 2011) studied the optimization design of shear wall of high-rise residential, he considered the dynamic characteristics and stress behavior of structures to optimize the structure. When the reinforcement ratio is fixed, the objective function is set to minimize the usage amount of concrete structures and constraint set is the maximum floor displacement angle. This method use zero-order optimization algorithm to obtain the optimal value of shear wall thickness to achieve structural optimization objectives. Shao Zhenqi (Shao Zhenqi, 2009) studies the optimization design of multi-layer steel frame structure, using first-order method and Optimization Toolbox used by ANSYS to establish a reasonable mathematical model, which improved efficiency and quality of design. Bo Tao (Bo Tao, 2012) studies structure optimization design in the light steel frame by merging the PSO algorithm with ACO algorithms to make fully use of these two algorithms. Feng Ying (Feng Ying, 2008) optimized three grid structure, using GDCAD, full of stress and genetic algorithms to optimize the design of the network structure, which is written in a paper concerned about grid structure design optimization. And finally with the help of optimization Toolbox of ANSYS she was able to study grid static structure optimization. Cao Hongtao (Cao Hongtao et al, 2008) selected a multi-objective optimization function as a tool to study different sections of steel - concrete composite beams in the steel-concrete composite beam multi-objective optimization research. As it is seen from large number of documents, there are many ways to optimize structure. There are a lot of valuable research results theoretically; however, the practical application of structural design optimization is far behind the theoretical achievement. How to come up with reasonable and efficient optimization methods is the main target of current structure design optimization project.

2 REINFORCED CONCRETE FRAME STRUCTURE OPTIMIZATION MODEL

2.1 *Beam Optimization Model*

Beams are typical flexural components. When we design flexural components, it is necessary to ensure that the item will not break take along the front section, but also to ensure that the item will not damage along the slanting section. Therefore, the calculation of bearing capacity of the front section and the slanting section is necessary. In the framework of which, cross sections of beams are usually rectangular. The paper optimized beams that have rectangular cross sections.

(1) Select variables of the design optimization

1) Cross section of beams

The cross section height of the beams is generally $1/14 \cdot 1/10$ of its span; The cross section width of the beam is generally $1/3$ of its height to ensure the lateral stability of the beam and the height ratio of beam cross-section should be no more than 4. After taking factors as deflection, load, actual construction, etc into account and taking 20mm, 50mm as modulus, initial sectional dimensions are as follows:

Beam Width:

$$b_b = \begin{Bmatrix} 200mm, 220mm, 250mm, 300mm, 350mm, \\ 400mm, 450mm, 500mm, 550mm, 600mm \end{Bmatrix} \tag{1}$$

Beam Height:

$$h_b = \begin{Bmatrix} 400mm, 440mm, 500mm, 550mm, 600mm, \\ 650mm, 700mm, 750mm, 800mm, 850mm \end{Bmatrix} \tag{2}$$

2) Cross-sectional reinforcement area of beam is A_{sb};

3) Cross-sectional reinforcement area of the left end of the beam is A_{sbz};

4) Cross-sectional reinforcement area of the right end of the beam A_{sby};

5) Ratio of the hoop limb to the stirrup spacing at the same cross-sectional area $\frac{A_{sbz}}{S}$.

In summary, the design variables of the reinforced concrete frame beams can be written as follows:

$$X = \left\{ b_b, h_b, A_{sb}, A_{sbz}, A_{sby}, \frac{A_{sbz}}{S} \right\} \tag{3}$$

(2) Construction of the objective function

The main objects that bear force of reinforced concrete frame structure are concrete beams (mainly under pressure) and steel (under tension and pressure). Considering reinforced concrete structures, the main factors that affect the cost of concrete is the amount of concrete, longitudinal force tendon length, stirrup length and hook lengths as well as the amount of template. Since templates can be consumed for several times and have a relatively small impact on the cost, then, we do not take them into account here. When we construct objective function, we only consider those have biggest impact on the overall cost as concrete section, longitudinal reinforcement section and stirrups section. In addition, this article do not take the impact of earthquake into consideration directly, we only adjust factors when we do calculation about stirrups to encrypt the beam column which consider the effect of seismic action indirectly.

The concrete cost of frame beam:

$$C_1 = m_c h_b b_b l_b \times 10^{-9} \tag{4}$$

Frame beam longitudinal reinforcement section cost:

$$C_2 = Pm_j \left[A_{sb} + \frac{1}{3}(A_{sbz} + A_{sby}) \right] I_b \times 10^{-9} \tag{5}$$

Frame beam stirrup part cost:

$$C_3 = Pm_g \frac{A_{svb}}{S} \left(I_b + 2 \times 1.5 h_b \right) \left(h_b + b_b - 4c_b + e_b \right) \times 10^{-9} \tag{6}$$

Frame beam unit cost:

$$C_i(X) = C_1 + C_2 + C_3 \tag{7}$$

And total cost of the frame beam:

$$C_{梁} = \sum_{i=1}^{m} C_i(X) \tag{8}$$

2.2 *Column optimization model*

In practical engineering, rectangular cross section is generally used in pillars frame structure, the vast majority of which has the same width and height. Under this situation, this paper let the column cross-section width b_z be equal to the column height h_z and we set modulus be equal to 50mm, which not only makes the process simplified, but also combine theory and practice to make the study more practical..

(1) Select to design optimization variables

1) The column cross-sectional dimension

"Seismic Design of Buildings" Article 6.3.5 says ratio of column height to width should not be more than 3; Then square columns are preferred. The initial column cross-section dimensions are shown as follows:

Column section width:

$$b_z = \begin{Bmatrix} 300mm, 350mm, 400mm, 450mm, 500mm, \\ 550mm, 600mm, 650mm, 700mm, 750mm \end{Bmatrix} \tag{9}$$

Column section height:

$$b_z = \begin{Bmatrix} 300mm, 350mm, 400mm, 450mm, 500mm, \\ 550mm, 600mm, 650mm, 700mm, 750mm \end{Bmatrix} \tag{10}$$

2) Cross-sectional reinforcement area of column is A_{sz}

3) Ratio of the hoop limb to the stirrup spacing at the same cross-sectional area $\frac{A_{syz}}{S}$

In summary, the design variables of the reinforced concrete frame columns can be written as follows:

$$X = \left\{ b_z, h_z, A_{sz}, \frac{A_{syz}}{S} \right\} \tag{11}$$

(2) Construction of the objective function

Since materials of reinforced concrete components are not uniform, we can not only do optimization of a single material, which makes the structure of the objective function with some difficulty. We have to think comprehensively, and list most realistic items into the optimization target to make the optimization more meaningful. Among all the reinforced concrete components, the main factors are the amount of concrete, longitudinal force tendon length, the stirrup length and hook length as well as the amount of template. When we construct the objective function we only take those have greatest impact toward costs as the concrete section, longitudinal reinforcement section and stirrups section into account, ignoring others.

Concrete cost of frame columns:

$$C_1' = m_c h_z b_z H_z \times 10^{-9} \tag{12}$$

Frame column longitudinal reinforcement section cost:

$$C_2' = P m_j A_{sz} H_z \times 10^{-9} \tag{13}$$

Frame column stirrup part cost:

$$C_3' = P m_g \frac{A_{svb}}{S} H_z \left(h_z + b_z - 4c_z + e_z \right) \times 10^{-9} \tag{14}$$

Frame column unit cost:

$$C_{柱} = \sum_{i=j}^{n} C_j(X) \tag{15}$$

3 REINFORCED CONCRETE FRAME STRUCTURE DESIGN OPTIMIZATION BASED ON GA

The decoding method for multivariate codec are as follows: design variables are represented by chromosome with a certain length; The space of design variables is connected by a bunch of chromosome. Since there are different structure needed to be optimized, the total length of the binary string related to each individual through the frame is different. The more the design variables, the greater the design variable space; for structural optimization, no matter the variables are continuous or discrete, this coding method is relatively simple to handle.

This article addresses the problem of discrete variables using binary coding method. The coding method is as follows:

Take four designs variables: the beam width, the beam height, the column width, the column height. The number of each variant were m, n, p, q. The binary substring length of each variable can be determined by discrete number, respectively were a, b, c, d. The total bit string length of the beam width is $q \times d$. After we connected all bit strings of these four variables sequentially, we get a complete chromosome. And the chromosome will represent an individual. When we do the decoding the bit string chromosome can be divided into beam width, beam height, column width and column height according to their length of bit strings. Then, we divide the bit strings of the beam width variable into m sections, the bit strings of the beam height variable into n sections, the bit strings of the column width variable into p sections, the bit strings of the column height variable into q sections. Each section represents a variable. According to relationship between the bit string and the decimal number, the bit string will be converted to a decimal number. Under different issues, according to certain mapping rule, we can mapped them to either discrete values or continuous values. Coding method is shown in Figure 1. $*$ represents 0 or 1 in the binary coding method.

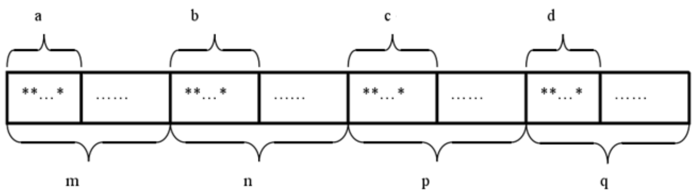

Figure1 Encoding method schematic

4 OPTIMIZATION DESIGN

In order to verify the feasibility of structural optimization program, we compared genetic algorithm and improved genetic algorithm. We selected calculations example to do the verification.

Te basic information is as follows: the frame structure is 2 crosses 2 layers; spans are both 5.0 meters; the heights are both 3.0 m; the grade of concrete is $C30$,the grade of steel strength is $HRB400$; the grade of stirrups strength is $HPB300$; the concrete unilateral price is 373 yuan / cubic meter; the steel price is 3650 yuan / ton; the forces information is as follows: the uniform constant load is $q_1 = 30kN/m$, the uniformly distributed live load is $q_2 = 10kN/m$, wind load cross-border nodes are: 15kN, 15kN, 15kN.

We will consider three conditions: constant load, live load, wind load; the original load combination 1 is $1.2X_D + 1.4X_L$. The original load combination 2 is $1.2X_D + 1.4 \times 0.7X_L + 1.4 \times 0.6X_W$, and the force bearing situation of reinforced concrete frame structure is shown as Figure 2.

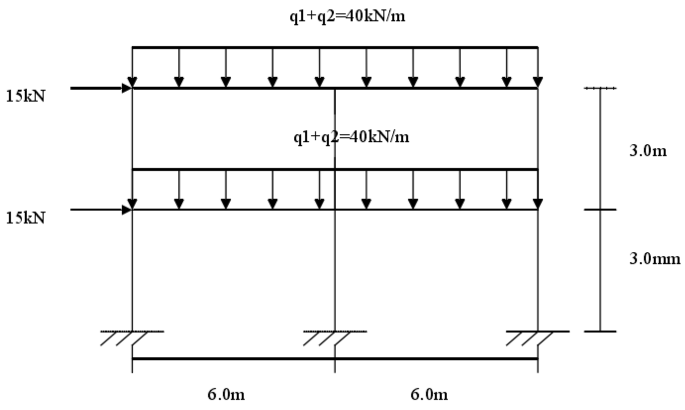

Figure 2 Reinforced concrete frame structure by trying to

We can see from the optimal results from Table 1 and Table 2 that the cross section of the column decreases and converge to the required minimum cross-sectional dimension. The structure reinforcement ration was the minimum required ratio of reinforcement; beam sizes that is the height-to-width ratio increases while the number of iterations increases and the reinforcement ratio decreases while the height-to-width increases. The total cost presented in this article following the normal design method was 3296.92 yuan. However, with the help of improved genetic algorithm to optimize the design, the total cost is 2808.24 yuan. And the total saving of cost is 488.68 yuan.

Table1 The optimization design results of the improved genetic algorithm column

Number	1	2	3	4	5	6
Cross section size	350×350	350×350	350×350	350×350	350×350	350×350
Stirrup	0.505	0.505	0.505	0.505	0.505	0.505
Stirrup price	29.31	29.31	29.31	29.31	29.31	29.31
Concrete column	0.368	0.368	0.368	0.368	0.368	0.368
Concrete column price	137.078	137.078	137.078	137.078	137.078	137.078
Longitudinal reinforcement	735	735	735	735	735	735
Longitudinal reinforcement price	63.18	63.18	63.18	63.18	63.18	63.18

Table2 The results of genetic algorithm optimization design of beam

Number	7	8	9	10
Cross section size	200×500	200×500	200×500	200×500
Stirrup	535.4 425.55 928.74	852.7 418.22 630.69	398.3 476.64 975.2	928 466.49 438.92
Stirrup price	130.884	130.752	133.016	132.105
Concrete column	0.412	0.388	0.438	0.436
Concrete column price	51.822	48.749	55.034	54.755
Longitudinal reinforcement	0.465	0.465	0.465	0.465
Longitudinal reinforcement price	173.445	173.445	173.445	173.445

5 CONCLUSION

This paper discussed the basic principles and characteristics of the basic genetic algorithm. In order to make up for the flaw of the basic genetic algorithm, we adopt adaptive crossover mutation strategy, the best individual retention policies, "elite" competitive strategy to improve it, and achieve good results. The improved genetic algorithm can be used to optimize the design of building structure making it possible to significantly reduce the cost of construction.

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