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Genetic Algorithm Application on Optimal Design of Strip Foundation

Li Hui*, Chen Zhuoyi and Zhou Mingji

School of Information Engineering, Handan College, Handan 056005, China

Abstract: According to the tedious design conditions and the difficulty to determine the optimal plan in underground foundation engineering design field at present, genetic algorithm was proposed and applied into the design of conventional reinforced concrete strip foundation. The coding method, operation procedure and penalty function of genetic algorithm were improved according to the specific issues. The project cost was selected as objective function, and bending resistance, shearing resistance and detailing requirements ruled by specification as constraint condition, the improved genetic algorithm was applied into optimization design. The results indicated that the algorithm can quickly converge to optimal solution. The optimal scheme was determined, which meet bending resistance, shearing resistance bearing capacity requirements, and construction conditions ruled by specification, at the same time project cost is lowest. This method reached to safety and economic double standard, and also improved the efficiency.

Keywords: Bending resistance, cost, genetic algorithm, optimal design, reinforced concrete, shearing resistance, strip foundation.

1. INTRODUCTION

Reinforced concrete strip foundation is widely used in the field of civil engineering. Conventional design method is that designers determine the width and height of foundation according to their design experience or past similar projects design, and then calculate foundation pressure whether to meet requirements for carrying capacity of foundation. The amount of steel bar is calculated according to the condition of bending and shear capacity. If it is not satisfy the requirements, and then the design plan will be modified until to meet specification requirements such as bearing capacity, rigidity and stability. This design procedure is tedious, and the design plan is usually a feasible solution, but it is not necessarily the optimal solution.

In order to enable the project to achieve the double standards of safety and economy, a number of researchers have proposed the concept of optimal design, and have made some achievements. The Lagrange multiplier method was used to optimize strip foundation under wall [1]. Liu X optimized the reinforced concrete plane component with genetic evolution algorithm [2]. Luo YJ optimized the stress of reinforced concrete structure with continuous topology optimization algorithm based on gradient [3]. The sequential linear programming method was used to optimize reinforced concrete beam [4]. The conventional design method is usually to determine the step size along a certain direction of iterative calculation, the calculation is very complex, and not easy to get the global optimal solution, it is always difficult to get application and popularization in the design field.

Genetic algorithm was proposed by J. Holland in 1975 at first, a professor of Michigan University, America. It is a global adaptive optimization algorithm [5], which mainly simulate the theory of biological evolution of nature, the thought of "survival of the fittest, survival of the fittest" to search the optimal solution. With the rapid development of computer technology, genetic algorithm has a high speed development from proposed to now. Genetic algorithm has many branches now, and has been applied to many fields, such as combinatorial optimization, machine learning, signal processing, adaptive control and artificial life [6-8].

This paper presents the application of genetic algorithm to the optimization of reinforced concrete strip foundation, which is widely used in civil engineering. This algorithm can provide structural designers an effective optimal design method, which not only guarantee safety and economic double standards, but also improve design efficiency.

2. GENETIC ALGORITHM AND ITS IMPROVEMENT

2.1. Essential Elements

Compared to other traditional optimization algorithms, genetic algorithm does not need profound derivation and other mathematical calculations, which is the use of bionics ideas, from lower to higher evolutionary optimization process. It also includes the basic elements of the design variables, objective function, constraint condition, but they are named by biological point of view, including individual, group, chromosome, the objective function, the fitness function, function and operation algorithms of punishment (including selection operator, crossover operator and mutation operator).

2.2. Coding Method and Its Improvement

The original genetic algorithm, which is also called the basic genetic algorithm, proposed by J.holland Professor,

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encode with binary coding method. The main advantage is convenient to encode and decode, and is easy to do theoretical analysis using schema theorem. But for a discrete unit, and a relatively large range, this coding method shows the limitation.

Most of design variables of reinforced concrete strip foundation are discrete, such as the diameter of steel, the optional values only have 6mm, 8mm, 10mm,…, a series of discrete integral value. If the steel bar diameter d is selected as a design variable, the value of d is one of them.

Improved genetic algorithm uses floating point coding method. Take the diameter of steel bar d for an example, the range of d is {6, 8, 10, 12, 14…}. In order to facilitate the operation, those discrete values were assigned to a one-dimensional array, as follows:

$$d(0) = 6;\ d(1) = 8;\ d(2) = 10; \ldots$$

Their index is a series of positive integer, such as 0,1,2,…. The indexes are corresponding to different values of array, and they can substitute them when generating initial variables, applying the selection operators, crossover and mutation operators. The process is similar to symbolic coding method, but the design variables are their real values, and the operators are applied to themselves. The method looks intuitive, and is convenient to operate. When applied to optimize reinforced concrete strip foundation, this method has high calculation efficiency.

2.3. Penalty Function and Conservation Measures of Individual Differences

The aim of the optimization is to reduce project cost under satisfy the safety and economic conditions.

Objective function:

$$F(X) = \min f(X) \tag{1}$$

X indicates design variable vector.

The constraint conditions are generally expressed as follows:

$$\begin{aligned} &h_j(X) = 0 \qquad j = 1,2,.....,k \\ &G_i(X) = 0 \qquad i = 1,2,.....,m \\ &X \geq 0 \end{aligned} \tag{2}$$

The objective function value of optimal individual is minimal in all individuals satisfy constrain conditions. If design variable vector X does not satisfy the constraint condition, the function value will be adjusted to a large value through the application of penalty function. As follows:

$$f(X) = const \tag{3}$$

Const indicates a very large number, at least larger than other function value an order of magnitude.

The fitness function value will be reduced, and the chance of being chosen will also be reduced.

If the individuals from the previous generation are not largely different, or the solution space is overly concentrated, then this algorithm may very likely fall into a local optimal solution. Besides the individuals not obeying the constraint, those with high similarity are also applied with the penalty function, which reserves the optimal individuals and reduces the adaptive values of other individuals. The similarity between individuals is expressed as Hamming distance. For two individuals X_i and X_j (length of chromosomes = *m*), then their Hamming distance is computed as:

$$\left\| X_i - X_j \right\| = \sqrt{\sum_{k=1}^{m} \left(x_{ik} - x_{jk}\right)^2} \tag{4}$$

During the operations, the designed variables in the chromosomes may differ in order of magnitude. Then to make the penalty operator more effective, the difference between two individuals can be rewritten as:

$$dis(X_i, X_j) = \sqrt{\sum_{k=1}^{m} \left(\frac{x_{ik} - x_{jk}}{x_{jk}}\right)^2} \tag{5}$$

when $dis(X_i, X_j) < L$, the fitness between two individuals is compared, and the individual with low fitness is treated with the penalty function.

$$F_{\min}\left(x_i, x_j\right) = Penalty \tag{6}$$

And then all the individuals will be sort by their final fitness function values. Those individuals will be chosen as a new generation, which have lesser objective function value than others.

2.4. Genetic Algorithm Optimization Procedure

The basic procedure of simple genetic algorithm is showed in Fig. (**1**). Firstly, N individuals were chose from population, and each individual contains n chromosome (design variable). Then the N individuals were applied selection

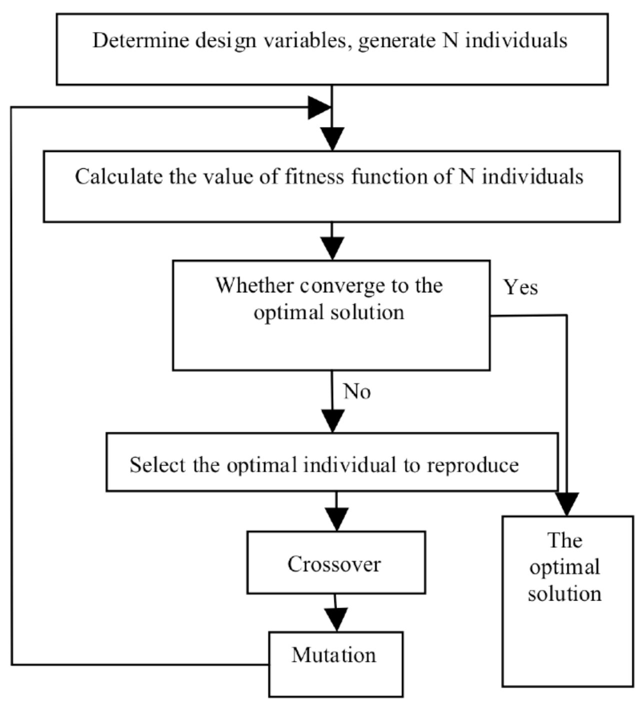

Fig. (1). Simple genetic algorithm flowchart.

operator, crossover and mutation operator. After that, judge each individual whether obey the constraint, then apply penalty function and calculate their fitness function value. Finally, sort the N individuals by their fitness function, judge the best individual whether meet end condition, if not, and cycle the above steps.

In the basic genetic algorithm, the selection operator, crossover operator and mutation operator are in series relation. The results show that at a very high crossover rate, the crossover operation damaged the relatively good individuals after selection operation. Also a very large mutation rate also damaged the previously identified better individuals. On the other hand, a too small crossover rate or mutation rate did not work effectively, and the convergence was slowed down. Based on this, the GA was improved, and the flow after improvement is showed in Fig. (**2**).

In the procedure of the improved GA, the individuals in the parent generation are self-copied twice before application of operators. Then each copy is applied with the selection, crossover and mutation operations. The 3*N* individuals are gathered for computation of fitness and ranking. The best *N* individuals are included into a new generation. At this moment, the crossover rate and the mutation rate were both regarded as 100%. Thereby, these *N* relatively good individuals from the parent generation will not be damaged by the subsequent operations, which utmost reserve the optimal individuals.

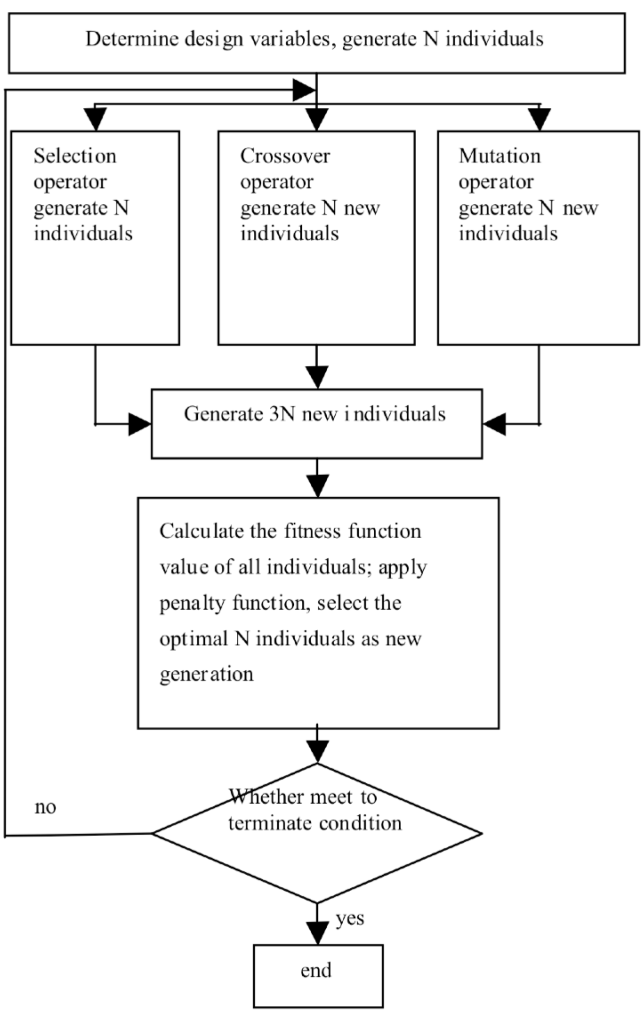

Fig. (2). Genetic algorithm calculation flowchart.

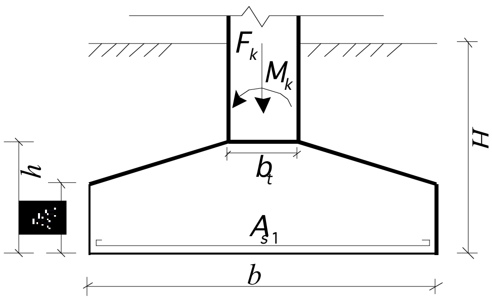

Fig. (3). Strip foundation sectional drawing.

3. OPTIMIZATION MODEL OF STRIP FOUNDATION

3.1. Design Variables

The sectional drawing of typical strip foundation is shown in Fig. (**3**). Designers usually select 1m in length direction as a unit to design and calculate.

If the top load of strip foundation is known, the vertical force is F_k, and the bending moment is M_k. we supposed that b_t indicates the width of wall, and H indicates the foundation embedment depth. The key variables contain the height of foundation h and width b, marginal height h_1 and steel bar amount in unit length A_{s1} (mm^2). They determine the plan of strip foundation, so we select them as design variables. As follows:

$$X_1(x_1, x_2, x_3, x_4) = X_1(h, b, h_1, A_{s1})$$

So the number of chromosome is 4. Each chromosome indicates a design variable of strip foundation, and the value of them must conform to the requirements of the specification. The height h and marginal height h_1 of foundation are not less than 200, and the values must be integer. The width of foundation b should larger than b_t. The value of A_{s1} is an integer greater than 0. A design plan is determined when these 4 chromosomes are given specific values in their solution space. According to the optimal procedure, N individuals were generated in 4 dimensional space, then loop to generate N optimal individuals. The most optimal individual is the optimal solution corresponds to the optimal design plan.

3.2. Objective Function

The aim of the optimization is to reduce project cost under satisfy the safety and economic conditions. We choose the cost in 1m unit as the objective function. It is mainly composed of two parts, concrete cost and steel bar cost. Express is as follows:

$$C_{\min} = [bh_1 + \frac{(b+b_t)(h-h_1)}{2}]\alpha_1 + bA_{S1}r_g\alpha_2 \tag{7}$$

where α_1 indicates the cost per cubic meter of concrete (Yuan/ m^3); α_2 indicates the steel cost per unit quality (Yuan/t); r_g is the density of steel bar (kg/m^3); other quantity as above.

3.3. Constraint Condition

Each individual is corresponding to one design scheme, and every design scheme should meet the requirement of specification. The main constraint conditions are as follows:

(1) The foundation bearing capacity, according to specification:

$$p_k \le f_a \tag{8}$$

$$p_{k\max} \le 1.2 f_a \tag{9}$$

where:

$$p_k = \frac{F_k + G_k}{A} = \frac{F_k}{b} + 20H \tag{10}$$

$$p_{k\max} = \frac{F_k + G_k}{A} + \frac{M_k}{W} = \frac{F_k}{b} + 20H + \frac{6M_k}{b^2} \tag{11}$$

(2) Bearing bending calculation

$$M_{\mathrm{I}} \le 0.9 A_{s1} f_y h_0 \tag{12}$$

where:

$$M_{\mathrm{I}} = \frac{1}{6}\left(\frac{b-b_t}{2}\right)^2 \left(2p_{\max} + p - \frac{3G}{b}\right) \tag{13}$$

$$G = 1.35 G_k \tag{14}$$

$p_{\max}$ — the maximum ground reaction force design values of foundation bottom edge corresponding to fundamental combination.

p — the ground reaction force design values of foundation bottom at wall edge corresponding to fundamental combination.

f_y — tensile strength design value of steel (N/mm^2);

$h_0 = h - 40$ mm, effective height of foundation

(3) Bearing shear calculation

$$V_s \le 0.9 \beta_{hs} f_t l_0 h_0 \tag{15}$$

where:

$$\beta_{hs} = \left(800 / h_0\right)^{1/4} \tag{16}$$

$h_0 = 800mm$, when $h_0 < 800mm$;

$h_0 = 2000mm$, when $h_0 > 2000mm$;

$l_0 = 1$ m.

V_s —the bearing shear design value of foundation at wall edge corresponding to fundamental combination;

$$V_s = \frac{b-b_t}{2} \cdot \frac{p_{\max} + p_{\min}}{2} \tag{17}$$

3.4. Fitness Function and Penalty Function

The fitness function is used to evaluate individual advantages and disadvantages, according to the above description; the larger the value of fitness function, the better the individual, and the cost is lower.

The penalty function will be applied to individual, if it does not obey the constraint conditions. The aim is to exclude it from the population. Besides, if two individuals are high similar, we will apply the penalty operator to the less disadvantage individual, so that the algorithm does not fall into a local optimal solution.

4. CASE STUDY

4.1. The Known Parameters

A reinforced concrete strip foundation under wall is designed as follows: the width of wall is 400mm, the concrete strength grade is C15, $f_t = 0.91 N/mm^2$, Igrade steel, and the tensile strength of steel $f_y = 210 N/mm^2$. The vertical force and bending caused by the upper wall on the top surface of strip foundation, the embedment depth and subgrade bearing capacity characteristic value are shown in Table **1**.

4.2. Optimization Calculation

Improved genetic algorithm optimal procedure of strip foundation was programmed using C language on VC++ platform.

The size of original population N=100. According to improved genetic algorithm procedure, the original N individuals will generate 3N individuals after selection, crossover and mutation. The chosen N individuals are the same to original generated N individuals. The other 2N individuals

Table 1. Known parameters of strip foundation.

f_k kN/m	M_k kN.m	H m	r_g kg/m^3	f_a kN/m^2	α_1 y/m^3	α_2 y/t
290	10.4	1.2	7850	160	400	5000

Table 2. The optimal plan.

	h m	b m	h_1 m	A_{s1} mm^2	
	0.35	2.6	0.2	1217	422.19

generated by crossover and mutation operator were completely different to original individuals, and the rate of crossover and mutation are equal to 100%. The more optimal N individuals were chose from the 3N individuals as new generation population. The most optimal individual is optimal solution.

With the generation in calculation, the most optimal individual in previous generation is becoming more and more optimal until stabilized to a low value. The design plan correspond to it is the most optimal plan. Though several optimal calculation to the above case, and the optimal solution convergent to a small value after about 40 generations. We think the solution is the most optimal plan. It was listed in Table **2**.

The most optimal solution conforms to all requirements of specification, and the project cost is lowest. Improved genetic can easily deal with this kind of design issues in civil engineering field.

5. CONCLUSION

Genetic algorithm was introduced into civil engineering and applied to optimize the reinforced concrete strip foundation. This kind of design issue has many tedious constraint conditions. According to this characteristic, the basic genetic algorithm was improved in aspects of procedure, coding and penalty operator. A case study was calculated using improved genetic algorithm in VC++ platform. The result showed that the method can effectively optimize reinforced concrete strip foundation. The next step is that the program will be packaged as software, which can be used by major designers.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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REFERENCES

[1] L. Liu, H.L. Zuo, and C.Q. Wang. “Optimum of reinforced concrete strip foundation under wall”, *Journal of Liaoning Technical University (Natural Science)*, vol. 33, no. 3, pp. 325-329, 2014.

[2] X. Liu, and W.J. Yi. “Reinforcement layout optimization of RC plane components”, *Chinese Journal of Computational Mechanics*, vol. 27, no. 1, pp. 110-114, 2010.

[3] Y.J. Luo, X.X. Wu, and Z.C. Deng, “Study on stress based topology optimization for reinforced concrete structures”, *Engineering Mechanics*, vol. 30, no. 6, pp. 22-29, 2013.

[4] J.J. Zhu, and T.J. Chen. “Optimization of steel reinforced concrete composite beam based on sequential linear programming method”, *Journal of ShangHai University (natural science)*, vol. 17, no. 2, pp. 203-208, 2011.

[5] M. Zhou and S.D. Sun. *The Principle and Application of Genetic Algorithm*, National Defence Industry Press, Beiing, 1999.

[6] X. Bian, and L. Mi. “Development on genetic algorithm theory and its applications”, *Application Research of Computers*, vol. 27, no. 7, pp. 2425-2429, 2010.

[7] L. Deng, J. Zhao, and X. Wang. “Genetic algorithm solution of network coding optimization”, *Journal of Software*, vol. 19, no. 8, pp. 2269-2279, 2008.

[8] Q. Liu, X.Y. Wang, Q.M. Fu, Z. Yong-Gang, and Z. Xiao-Fang. ”Double elite coevolutionary genetic algorithm”, *Journal of Software*, vol. 23, no. 4, pp. 765-775, 2012.

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