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APPLICATION OF GENETIC ALGORITHM IN MESHLESS OPTIMIZATION OF ELASTIC FOUNDATION WITH RIBBED PLATES AND BEAMS

XIAOMEI LIU*

Abstract. In order to overcome the mesh dependency of finite element method, the author proposes the application of genetic algorithm in meshless optimization of elastic foundation with ribbed plates and beams. The ribbed plate is regarded as a combination of plates and beams. Based on the meshless method and combined with genetic algorithm, the rib arrangement position of the rectangular ribbed plate is optimized to minimize the deflection of the center point of the ribbed plate under lateral load. Compared to traditional finite element methods, using the author's meshless method for rib position optimization analysis of ribbed plates does not require mesh reconstruction, and the nodes discretized on the plate and ribs always do not need to be changed. The results indicate that the deflection values of the center points corresponding to the second generation individuals are more concentrated, and there are also many individuals with smaller deflection values compared to the first generation. The hybrid genetic algorithm is indeed effective. The author added the constrained random direction method to form a hybrid genetic algorithm based on genetic algorithm, which accelerates convergence speed, reduces computational repetition rate, and significantly reduces the computational algebra of genetic algorithm to two or three generations, resulting in better results.

Key words: Meshless method, Ribbed plate optimization, Minimum moving multiplication, Hybrid genetic algorithm

1. Introduction. As a commonly used structural form in engineering, the mechanical performance analysis of plate and shell structures has always been a hot topic in computational mechanics. Since the initial classical mechanical analysis theory of plates and shells, many experts and scholars have shown great interest in plate and shell structures. With the improvement of industrial production level and the gradual deepening of Internet technology, research on plate and shell structures has emerged in endlessly [1]. Plate shell structure on elastic foundation is also a common structural style in engineering, such as raft foundation of buildings, rigid concrete pavement, runway for aviation flight, etc. In practical engineering, plate and shell structures based on this foundation are usually subjected to single or combined loads, such as uniformly distributed loads, moving loads, and so on. Maintaining the stability of plate and shell structures on elastic foundations under complex load conditions is crucial for engineering. Compared to previous engineering structures, flat plates often encounter problems of insufficient stiffness and bearing capacity in practical applications [2]. If the stiffness is improved by increasing the thickness of the plate, it will also result in excessive weight of the plate and low economic benefits. Ribbed plate is a method of increasing the local stiffness and stability of the foundation plate by adding ribs [3]. Therefore, combining the ground substrate with ribs is an effective form of shell structure to resist excessive local deformation. At present, many scholars at home and abroad have conducted a lot of research and analysis on the mechanical calculation of plate and shell structures on elastic foundations. However, there is relatively little research on the addition of ribbed plates to elastic foundations. Due to the presence of ribs, problem analysis will be more complex than plate problem analysis, and different numbers and positions of ribs will affect the overall mechanical performance of ribbed plates [4]. For different load conditions, the reasonable arrangement and optimization of the rib positions of ribbed plates on elastic foundations. Currently, many scholars at home and abroad have conducted a lot of research and analysis on the mechanical calculation of plate and shell structures on elastic foundations, but there is relatively little research on the aspect of ribbed plates on elastic foundations, due to the presence of ribs, problem analysis will be more complex than flat plate problem analysis, and different numbers and positions of ribs will affect the overall mechanical performance of the ribbed plate [5]. The rational arrangement and optimization of the rib positions for adding ribbed plates on elastic foundations under different load conditions can enhance the local stiffness

*Xuchang Vocational Technical College, Xuchang Henan, 461000, China (Corresponding author, XiaomeiLiu5@126.com)

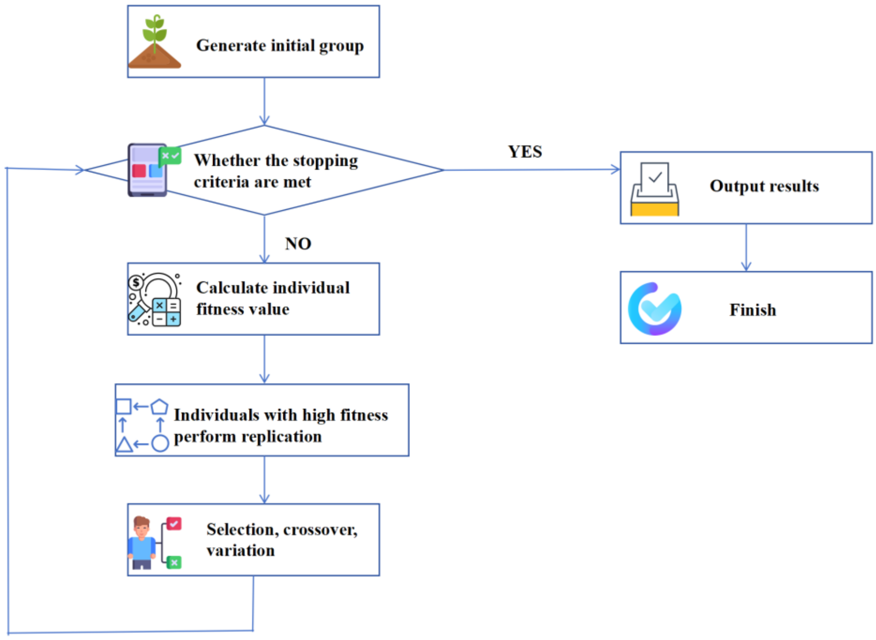

Fig. 1.1: Genetic Algorithm

and safety performance of the structure, which has certain theoretical significance and engineering reference value for the research of adding ribbed plates on elastic foundations [6]. As shown in Figure 1.1:

2. Literature Review. Many scholars at home and abroad have conducted extensive research on ribbed plates. In the early stages of the research, the research model on ribbed plates went through a period of exploration. In the initial research, many scholars regarded the ribbed plate as a uniformly dense plate, and the ribs became attached and adhered to the initial flat plate. This model is called the orthogonal anisotropic plate model. Subsequently, it was discovered that the seed delivery model was only suitable for ribbed plates with dense rib arrangements, so improvements were made to this model, resulting in the Grillage model. Although the principle is clear and the formula is simple, satisfactory solutions cannot be obtained for most ribbed plates. Later scholars tended to consider ribbed plates as a hybrid structure, with the original plate being calculated as a plate and the ribs as a beam model.

In the bending analysis of ribbed plates, Tan, C. first analyzed the stability of ribbed plates under uniformly distributed loads using the energy standard [7]; In order to prevent local deformation of the ribbed plate, Ahmad, H., Hashim derived a relationship about the minimum size range of longitudinal ribs. With the development of technology, methods such as finite strip method and finite element method have also been applied to the bending of ribbed plates [8]. The Rayleigh Ritz method is also used in the bending analysis of ribbed plates, and many scholars have made significant contributions in this regard. Patel, V. G. solved the linear bending problem of rectangular ribbed plates using first-order shear deformation theory and moving least squares approximation [9]; Rasoulizadeh, M. N. analyzed the transverse bending of rectangular ribbed plates using Huber theory and considering the effect of mid plane strain, and calculated the bending problem of unidirectional ribbed plates under local loads using the mixed trigonometric series method [10]; Lin, J. conducted a structural analysis of ribbed plates under the combined action of compression and bending loads, based on the application of the principle of minimum potential energy and considering the comprehensive effect of shear lag and shear deformation in the calculation process, laying a good foundation for calculating the concrete main cable-stayed bridge [11].

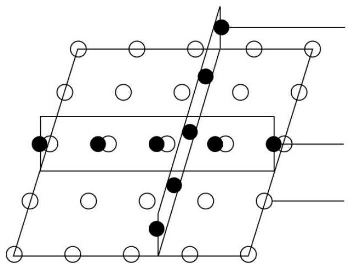

Fig. 3.1: Mesh free model with ribbed plates

The author combines genetic algorithm with constrained random direction method to form a hybrid genetic algorithm. The hybrid genetic algorithm combines the advantages of constrained random direction method and genetic algorithm, and optimizes the calculation results of each generation of genetic algorithm using constrained random direction method. The author uses a hybrid genetic algorithm and a meshless model based on a ribbed plate structure to optimize the rib arrangement of the ribbed plate. The effectiveness of the proposed method is verified through numerical examples.

3. Research Methods.

3.1. Mesh free model with ribbed plates. The meshless model with ribbed plates is shown in Figure 3.1.

From Figure 3.1, it can be seen that the arrangement of nodes on the x-axis and y-axis ribs does not follow the position of the nodes on the board, but is distributed between two rows or two columns of nodes on the board. According to the moving least squares approximation, the expression of the shape function can be obtained 3.1:

$$N(x,\overline{x}) = P^T(\overline{x})A^{-1}(x)B(x) \tag{3.1}$$

Among them: $P(x)$ is the basis function matrix; $A(x), B(x)$ is a matrix composed of a weight function and a basis function, respectively. The displacement field function of the plate can be obtained from the moving least squares approximation and first-order shear deformation theory as follows 3.2:

$$\begin{cases} u_p(x,y,z) = \sum_{l=1}^{n} N_l(x,y)u_{0pl} - z\sum_{l=1}^{n} N_l(x,y)\varphi_{pxl} \\ v_p(x,y,z) = \sum_{l=1}^{n} N_l(x,y)u_{0pl} - z\sum_{l=1}^{n} N_l(x,y)\varphi_{pyl} \\ w_p(x,y,z) = \sum_{l=1}^{n} N_l(x,y)w_{pl} \end{cases} \tag{3.2}$$

Among them: $u_{0pl}, v_{0pl}, \varphi_{pxl}, \varphi_{pyl}$ and w_{pl} are the node parameters of the board; n represents the number of board nodes. The displacement field function of the x-axis rib is as follows 3.3:

$$\begin{cases} u_{sx}(x,z) = u_{0s}(x) - z\varphi_{sx}(x) \\ = \sum_{l=1}^{N} \phi_{xl}(x)u_{0sl} - z\sum_{l=1}^{N} \phi_{xl}(x)\varphi_{sxl} \\ w_{sx}(x) = \sum_{l=1}^{N} \phi_{xl}(x)w_{sxl} \end{cases} \tag{3.3}$$

Among them, u_{0sl}, φ_{sxl}, and w_{sxl} are the displacement field parameters of the x-axis ribs; N is the total number of nodes on the ribs; ϕ_{xl} is a shape function. Similarly, similar expressions also apply to ribs in the y-direction.

3.1.1. Displacement coordination conditions. The displacement between the ribs and the plate on the ribbed plate has the following relationship. The following equations 3.4, 3.5, and 3.6:

$$[w_p]_p = [w_{sx}]_s \tag{3.4}$$

$$[\varphi_p]_p = [\varphi_{sx}]_s \tag{3.5}$$

$$[u_p]_p = [u_{sx}]_s \tag{3.6}$$

Among them, point p is the point on the mid plane of the plate corresponding to node s on the rib; The point c is the intersection of the line connecting node s on the rib and point p on the plate with the contact surface. Substituting equations 3.2 and 3.3 into equations 3.4 to 3.6 yields the following equations 3.7, 3.8, and 3.9:

$$\sum_{I=1}^{n} N_I(x_i, y_i) w_{pI} = \sum_{J=1}^{N} \phi_{xJ}(x_i) w_{sxJ} (i = 1, \cdots, N) \tag{3.7}$$

$$\sum_{I=1}^{n} N_I(x_i, y_i) \varphi_{pI} = \sum_{J=1}^{N} \phi_{xJ}(x_i) \varphi_{sxJ} (i = 1, \cdots, N) \tag{3.8}$$

$$\sum_{I=1}^{n} N_I(x_i, y_i) u_{0pI} + e \sum_{I=1}^{n} N_I(x_i, y_i) \varphi_{pxI} = \sum_{J=1}^{N} \phi_{xJ}(x_i) u_{0SJ} (i = 1, \cdots, N) \tag{3.9}$$

Represented by a matrix as follows 3.10, 3.11, and 3.12:

$$T_p \delta_{p\varphi} = T_{sx} \delta_{ex\varphi} \tag{3.10}$$

$$T_p \delta_{pw} = T_{sx} \delta_{exw} \tag{3.11}$$

$$T_p \delta_{pu} + e T_p \delta_{px\varphi} = T_{sx} \delta_{su} \tag{3.12}$$

where e represents the distance between the neutral plane of the plate and the neutral axis of the ribs. Multiplying both ends of the equation by T_{sx}^{-1} can simplify the three equations above into the following equation 3.13:

$$\delta_{sx} = T_{spx} \delta_p \tag{3.13}$$

Among them, equation 3.14 is as follows:

$$\begin{aligned} \delta_{sx} &= [u_{0s1}, w_{sx1}, \varphi_{sx1}, \cdots, u_{0sN}, w_{sxN}, \varphi_{sxN}]^T \\ \delta_p &= [u_{0p1}, v_{0p1}, w_{p1}, \varphi_{px1}, \varphi_{py1}, \cdots, u_{0pn}, v_{0pn}, w_{pn}, \varphi_{pxn}, \varphi_{pyn}] \end{aligned} \tag{3.14}$$

T_{spx} is a matrix of $3N \times 5n$, and when the position of the ribs changes, only the matrix needs to be recalculated, without the need to redistribute the plate nodes [12]. Optimizing the arrangement of ribs inevitably involves frequent changes in the position of the ribs. Based on the meshless model mentioned above, there is no need to redraw the plate mesh at each step of the optimization process like the finite element method, which can greatly reduce computational complexity. There is a similar relationship between y-shaped ribs and x-shaped ribs, which will not be repeated here.

3.1.2. Control equation. According to the first-order shear deformation theory, the potential energy of a ribbed plate can be expressed as follows 3.15:

$$U_p = \frac{1}{2} \iiint_{-h_p/2}^{h_p/2} \epsilon_p^T D \epsilon_p dz dx dy + \frac{1}{2} \iint \frac{G h_p}{k} (\gamma_{pxz}^2 + \gamma_{pyz}^2) dx dy \tag{3.15}$$

Among them, h_p represents the thickness of the ribbed plate; ϵ_p, γ_{pxz} and γ_{pyz} represent the strain matrix of the ribbed plate; D, G represents the elastic matrix and shear matrix of the ribbed plate, respectively; K=56 represents the shear correction coefficient.

The potential energy of x-shaped ribs can be expressed as follows 3.16:

$$U_{sx} = frac12 \iint_{-h_{sx}/2}^{h_{sx}/2} E(u_{0s,x} - z\varphi_{sx,x})^2 W_{sx} dzdx + \frac{1}{2}\int \frac{GA_{sx}}{k}(w_{sx,x} - \varphi_{sx})^2 dx \tag{3.16}$$

Among them: E represents the elasticity matrix; W_{sx} represents the width of the ribs; A_{sx} represents the cross-sectional area of the rib. The potential energy of the y-shaped ribs can be expressed similarly, so the total potential energy of the ribbed plate can be expressed as follows 3.17:

$$U = U_p + U_{sx} + U_{sy} \tag{3.17}$$

According to the principle of virtual work, the control equation for ribbed plates can be obtained as follows 3.18:

$$K\delta_p = f \tag{3.18}$$

where: K is the stiffness matrix; f is the load vector.

3.1.3. Complete conversion method. The meshless method using moving least squares fitting does not satisfy the Kronecker condition, so the displacement boundary cannot be directly applied. The author proposed this concept using the complete transformation method, which is a very effective method for handling boundary conditions in Galerkin's method. After being processed by the complete transformation method, boundary conditions can be directly applied like the finite element method [13].

3.2. Hybrid Genetic Algorithm. Genetic algorithm has the disadvantages of high computational complexity and high repetition rate, but it has the global optimization characteristics that numerical optimization methods do not possess, while constrained random direction method has the disadvantages of strong local optimization and weak overall optimization ability. By combining these two algorithms and taking advantage of each other's strengths, a new hybrid optimization method, namely the hybrid genetic algorithm, is obtained.

3.2.1. Genetic Algorithm. For optimization problems with constraints, they can generally be described as follows 3.19:

$$\begin{cases} max f(x) \\ s.t. X \in R \\ R \subseteq U \end{cases} \tag{3.19}$$

Among them: X is the design variable; f(X) is the objective function; U is the basic design space; R is a set of feasible solutions composed of all solutions that satisfy the constraint conditions.

The optimization of ribs with ribbed plates is particularly effective in this case, as its sensitivity to the objective function is not easy to obtain and the computational scale is relatively small. The development of genetic algorithms relies on the improvement of computational level and the development of interdisciplinary fields, simulating the evolutionary process of biological populations - the crossover and mutation between chromosomes - to encode data in practical problems and perform a series of operations on the encoded data.

Genetic algorithm is a method of binary encoding design variables, followed by operations such as crossover, inheritance, and mutation to modify individuals, and then using the values of fitness functions to filter [14]. After multiple iterations, individuals who make the objective function better are obtained.

A pattern is a small combination that has undergone crossover and mutation without changing the encoding order. According to the pattern theorem of genetic algorithm, it can be known that good patterns will grow exponentially with the increase of iteration times, while according to the assumption of building blocks, better modules can be pieced together during the iteration process to form better individuals. The genetic algorithm, which adopts the strategy of preserving the best individual, accumulates excellent patterns and the probability of obtaining the best result is 1. From this, it can be inferred that as long as the algebraic selection of the genetic algorithm is large enough, the genetic algorithm that adopts the strategy of preserving the best individual will converge to the optimal solution.

3.2.2. Constrained Random Direction Method. The basic idea of the constrained random direction method is to generate random directions for searching within a feasible range that satisfies the constraint conditions. The basic operating steps are:

1. Generate a random point within the feasible domain;
2. Generate a series of random directions around a random point as the center;
3. Find points along these directions that can make the objective function better;
4. Repeat steps 1 to 3. The initial point is randomly generated by the computer.

The termination condition of optimization design iteration is an important component of selecting optimization design. The author chooses the function descent criterion as the termination condition for the iteration of the constrained random direction method [15,16]. Use the value of the objective function in two adjacent iteration processes to determine whether the program can be terminated. When the difference between two adjacent objective function values is less than the given acceptable iteration accuracy, the iteration terminates.

3.2.3. Using Hybrid Genetic Algorithm to Optimize the Program Flow of Ribbed Plate. The working principle of hybrid genetic algorithm is to first use genetic algorithm for calculation, obtain the contemporary optimal solution, and then use constrained random direction method to find the local solution near this point. Due to the strong dependence of the constrained random direction method on the selection of initial points, the probability of obtaining an approximate optimal solution from the constrained random direction method after obtaining a contemporary better solution through genetic algorithm will increase. The process of using hybrid genetic algorithm to calculate ribbed plates is as follows:

1. Determine design variables, set population size and iteration times, and select numerical values for crossover probability and mutation probability.
2. Scatter nodes and Gaussian points in the design area.
3. Loop the background grid points and calculate the shape function values at each calculation point.
4. Integrate the stiffness matrix of the plate and beam in the ribbed plate.
5. The position of the ribs during the optimization process is a design variable that constrains the movable range of the design variable. Set the binary encoding method to keep the design variables within the constraint range, and design the encoding length and sequence according to the required accuracy [17,18].
6. Utilize genetic algorithm for optimization, generate corresponding populations, and perform decoding operations on the populations to obtain actual design variable values.
7. Calculate the unique transformation matrix based on the values of the design variables, and combine it with the stiffness matrix of the ribs and plates calculated in step 4) to form the total stiffness of the ribbed plate.
8. Perform meshless analysis to obtain the deflection of the center point of the ribbed plate.
9. Compare the fitness function values of each individual to obtain the best individual in the current population and all populations so far. Adopt the optimal preservation strategy and replace the worst individual in the current population with the best individual so far.
10. Obtain the optimal individual and perform constrained random direction method optimization operation.
11. Perform selection operations on genetic algorithms. If the proportional selection method is used, the ratio of the fitness of each individual to the fitness of the entire population is the probability of an individual entering the next generation; If a deterministic sampling selection method is used, the fitness value is used to calculate the expected value of each individual's ability to survive in the next generation population, and this expected value is used to select individuals who can enter the next generation.
12. Perform crossover operations on genetic algorithms. Using a single point crossover method to exchange binary codes between two adjacent genes.
13. Perform genetic algorithm mutation operations. Using the method of basic positional variation, randomly assign gene values on one or several loci for mutation operations [19,20].
14. Generate the next generation of new individuals.
15. Determine whether the iteration termination condition is met. If it is met, the iteration stops. If it is not met, return to step 6) to continue the calculation.

Table 4.1: Analysis of Optimization Results of Vertical Rib and Rib Plate Hybrid Genetic Algorithm

Serial Number	x-direction rib position/m	y-direction rib position/m	Plate midpoint deflection/$10^{-5}m$	Relative error/(%)
1	0.498757	0.494321	7.837	0.06
2	0.507341	0.505817	7.843	0.08
3	0.495716	0.505312	7.841	0.08
4	0.517681	0.476218	7.885	0.64
5	0.509646	0.498761	7.844	0.08
6	0.497374	0.505842	7.838	0.07
7	0.497894	0.504423	7.838	0.06
8	0.502065	0.494346	7.837	0.07
9	0.510039	0.500435	7.843	0.08
10	0.494728	0.488582	7.846	0.14

Hybrid genetic algorithm introduces constrained random direction into the framework of genetic algorithm. Since the constrained random direction method can find better results each time than the previous one, it can accelerate the efficiency of genetic algorithm in finding better solutions without changing its convergence.

4. Result analysis.

4.1. Example verification. Take a ribbed plate with two perpendicular ribs for calculation. The ribbed plate has a thickness of 0.2m and a square plate with a length and width of 2m. The two ribs have the same size, with a height of 0.2m and a width of 0.02m. The meshless method arranges nodes as 8. In order to ensure population diversity, the population size is set to 21, the crossover probability is set to 0.54, and the mutation probability is set to 0.06. Ribbed plates are subjected to uniformly distributed lateral loads, with a magnitude of 2Pa and fixed boundary conditions on all four sides. Take the computational algebra of genetic algorithm as the second generation and optimize the placement of ribs in the ribbed plate. It is known that under the action of uniformly distributed loads, the optimal placement position for the ribs of a vertical ribbed plate is near the centerline of the plate. The optimization goal is to increase the deflection value of the center point of the ribbed plate, and the constraint is the length and width of the ribbed plate. As a control, the cross shaped ribs distributed at the centerline were calculated, with a deflection value of 7.836×10^{-5} at the center point. The results of hybrid genetic algorithm optimization are shown in Table 4.1 [21,22].

Through calculation, it can be seen that the results of using the hybrid genetic algorithm for two generations are both near the centerline position of the plate, and the error of the deflection at the center point of the cross intersecting rib and the rib position at the centerline of the plate is within an acceptable range, which proves the effectiveness of the hybrid genetic algorithm.

4.2. Optimization of Double Vertical Rib and Ribbed Plate Rib Layout under Local Load. The height of the two vertical ribs of a square with ribs is h_s=0.2m, the width of the ribs is w_S=0.02m, the edge length of the slab is L=2m, and the thickness of the slab is h=0.02m. The elastic modulus of both the plate and ribs is taken as E=18GPa, with a Poisson's ratio of μ=0.4, under the action of a local load (2Pa) of a quarter to the left and bottom of z. The meshless model adopts 8×8 uniformly distributed nodes for discretization, with fixed supports on all four sides. The optimization objective is to obtain the deflection value at the center point of the ribbed plate, with constraints on the length and width of the ribbed plate [23,24]. In the hybrid genetic algorithm, the crossover probability is set to 0.5, the mutation probability is set to 0.06, and the iteration number is two generations [25,26]. When the y-axis rib position is 0.73456 and the x-axis rib position is 0.433293, the deflection at the midpoint of the plate is the smallest (0.90896). The variation of its value is shown in Figures 4.1 to 4.2.

As shown in Figure 4.1, the optimal distribution is in the fourth quadrant. In the second generation, the distribution of numerical points in the fourth quadrant appears to be significantly denser than in the first generation, with more individuals approaching the optimal solution. The deflection values of the center points of each individual in each generation of the population are shown in Figures 4.3 to 4.4. As shown in Figure 4.2, the

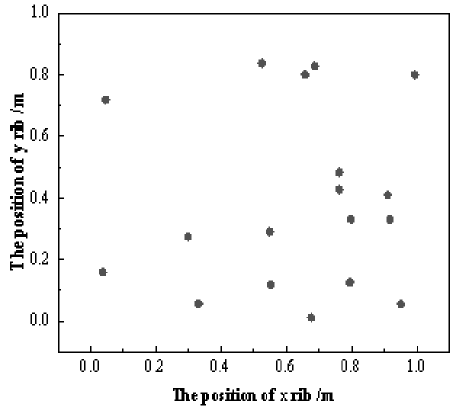

Fig. 4.1: Distribution of rib positions in the first generation of individuals

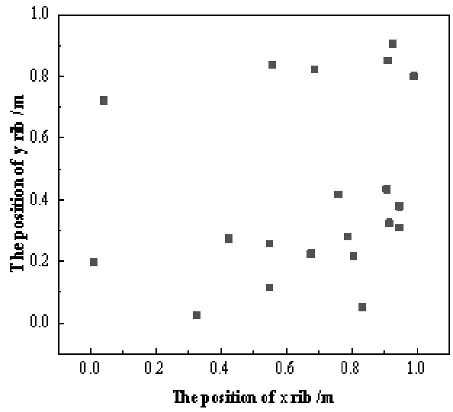

Fig. 4.2: Second generation individual rib position distribution map

deflection values of the center points corresponding to the second generation individuals are more concentrated, and there are also many individuals with smaller deflection values compared to the first generation. The hybrid genetic algorithm is indeed effective and can be gradually improved by adding computational examples in the future.

5. Conclusion. The author calculated the ribbed plate based on the meshless method, taking advantage of the advantage that the meshless method does not require element division to optimize the placement of ribs on the ribbed plate, and proposed a new optimization method. The main advantages and results of this method are as follows:

1. The use of meshless methods does not require reconstruction of the nodes distributed on the ribbed plate surface and ribs, greatly reducing the computational complexity of the optimization process.
2. The genetic algorithm was mixed with the constrained random direction method, and the global search was performed using the genetic algorithm. The local search characteristics of the constrained random direction method were used to optimize the placement of ribs when the ribbed plate was subjected

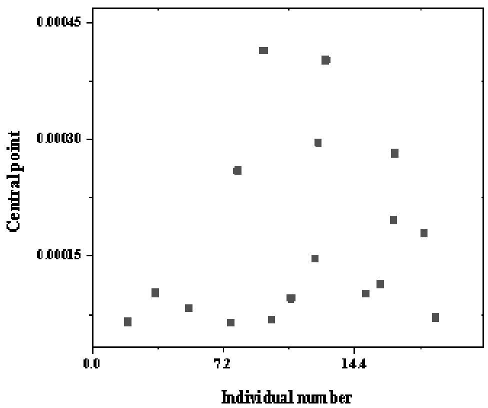

Fig. 4.3: Center point deflection values corresponding to the first generation of individuals

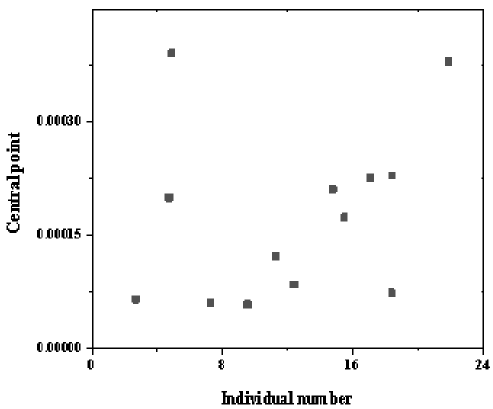

Fig. 4.4: Center point deflection values corresponding to the second generation individuals

to lateral loads, after obtaining the calculation results of the genetic algorithm, further optimization operations can be carried out using the constrained random direction method, which not only greatly reduces the computational complexity of the genetic algorithm, but also improves the computational effectiveness of the constrained random direction method. A simple genetic algorithm requires more computational algebra for optimization operations, while the author's example can achieve better results in fewer computational algebras, proving the effectiveness of the hybrid genetic algorithm.

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