Research Article

Mechanical Performance Analysis of Steel-Timber Structure System with Reinforced Layer Based on Particle Algorithm

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With the continuous development of science and technology, the state attaches great importance to industry, and the research on materials by researchers is getting more and more in-depth. The steel-wood structure is one of the material structures that has been focused on. The steel-timber composite (STC) structure has the characteristics of good mechanical performance, sustainable attributes, and lightweight. For the steel-timber structure with reinforced layer, its mechanical performance is better, stronger, and more durable. Particle algorithm (PSO for short) is an intelligent search algorithm derived from simulating the foraging behavior of birds. The PSO algorithm uses the information exchange ability of the population to search for the problem to obtain the optimal solution. The purpose of this paper is to study the mechanical properties of steel-timber structural systems with reinforced layers. In this paper, an improved PSO algorithm is proposed, and the algorithm model is used to conduct static tests on steel-timber structures with reinforced layers. The experimental results in this paper show for A and B two different steel-timber specimens with reinforced layers. When the number of reinforced layers of the A specimen is twice that of the B specimen, the stagnation amplitude of the B specimen is twice that of the A specimen. The cumulative energy consumption of A will be relatively more, in every 1 mm of displacement. A specimen is 4.6 kN·mm on average than B specimen, and the damping coefficient of A specimen is 0.028 larger than that of B specimen. This shows that for specimens with more reinforced layers, the higher the ultimate fatigue strength, the stronger the bearing capacity and the better the stability.

1. Introduction

As for the exploration and research of steel-timber composite structure, the future is bright. Timber is energy-saving, environmentally friendly, and renewable. The layout of timber in buildings is flexible and the forms are diverse. And it is relatively easy to change the internal structure of the building according to the actual needs. The steel structure has good ductility and strong seismic deformation ability. The steel-timber composite structure has better mechanical performance and is stronger and more durable. Reinforcement layer refers to the use of reinforcement method to make steel bar layer. Reinforcement method refers to sinking reinforcements (gravel piles, sand piles, tree root piles, etc.) in soft soil or laying geopolymers as reinforcement in artificially filled embankments and retaining walls. This enables this artificial composite soil to withstand tensile, compressive, and shearing effects. This in turn increases the bearing capacity of the foundation, reduces settlement, and increases soil stability.

Particle swarm optimization algorithm is an evolutionary algorithm based on population iteration. By sharing information among individuals, the optimization of complex problems is realized in a collaborative manner. But it does not have the selection, crossover, and mutation operators in genetic algorithms. It is to find the optimal solution by the particle following the position of the optimal particle in the population. Like other adaptive evolutionary algorithms based on population search, the PSO algorithm has problems such as slowing down of the convergence speed and easy to fall into local extreme values in the later stage of evolution.
At present, there are no mature analytical tools and methods for the theoretical analysis of the convergence of the particle swarm optimization algorithm. The convergence analysis of the basic particle swarm optimization algorithm and its improved algorithm is mostly based on the actual simulation experiments of the algorithm and the analysis of the solution is the effect of the algorithm. Therefore, the improved particle algorithm proposed in this paper can solve the problems of slow convergence speed and easy to fall into local extremum. This is of great value to the main content of this study.

With the continuous development of science and technology and the continuous innovation in the industrial field, more and more scholars conduct in-depth research on composite structures and materials. EWECS (Engineering Wood Encased Concrete-Steel) composite structural system consists of concrete, steel, and glue-laminated wood. In the experimental study of EWECS columns and EWECS beam-column joints, it was confirmed that the EWECS structural system has good and stable hysteresis characteristics. Among them, Suzuki performed static load tests and three-dimensional (3D) finite element analysis on the internal joints of EWECS column-beam and plates to study the structural performance and tested four 1/2 scale EWECS column-beam beams with inner seams. Finite element analysis uses mathematical approximation to simulate real physical systems. It uses simple but interacting elements (i.e., units) to approximate the real system of infinite unknowns with a finite number of unknowns. Finite element analysis is to replace complex problems with simpler problems and then solve them. It treats the solution domain as consisting of many small interconnected subdomains called finite elements. The results showed that the concrete in the connected panels would generate high compressive stresses regardless of the restraint of the reinforcement due to the compressive forces transmitted by the slab concrete [1]. Kyvelou presents the results of a numerical study on the degree of composite action that can move within a flooring system including cold-formed steel joists and timber-based particleboard and developed finite element models and examined about 100 systems in total. The model includes initial geometric imperfections, load-slip responses of fasteners used to achieve shear connections, and geometric and material nonlinearities. The identified significant benefits in terms of structural responses were obtained from the presented numerical studies due to comprehensive actions. The research revealed substantial progress in the structural properties of this novel form of composite structure and the impact of key control parameters [2]. Zeitz used manual material counts from construction documents for four one-way span parking garages, one precast concrete, one post tensioned concrete, one porous steel, and one wood. The comparison showed that there was little difference in the embodied carbon and energy of the structural systems used in the parking lot under the optimal material specification [3]. Li presented the calibration of performance targets and the development of a performance-based design method for timber-steel hybrid structures. The structure consists of a flexural steel frame and prefabricated infill balsa structural timber shear walls. Li obtained the interlayer drift limit for the collapse-prevention performance level by incremental dynamic analysis (IDA). Interlayer drift is used as an indicator of structural or nonstructural damage. Considering the energy dissipation capability during earthquakes, Li performed a semistatic cycle analysis. He studied the hysteresis properties and damping effects of timber-steel hybrid structures. Li proposed an expression to determine the equivalent viscous damping of this structural system. Li developed a design procedure based on direct displacement and illustrated the design procedure with a design example of a timber-steel hybrid structure. This bridges the gap between a series of experimental and theoretical studies and the engineering application of innovative timber hybrid structural systems [4]. Al-Sammari presents the results of finite element analysis and parametric studies of a connector: a perforated steel plate, half of which is glued in the path of the timber members and the other half embedded in the concrete slab. Wooden concrete composites are structural deck systems. It benefits from the use of wood materials for a lightweight, sustainable substructure and the use of concrete as a wear-resistant, vibration-damping top layer element. These systems use shear connectors to transfer shear stress between wood and concrete. This results in a fully or partially compounded action that increases strength and stiffness. Al-Sammari’s study concluded that thickness predictably affects the shear capacity of the connector as well as ductility and stiffness (sliding modulus). However, with respect to the buried depth of the connector, it was found that in concrete and timber, higher stresses were mainly generated within the buried depth of about 30 mm. This suggests that lower values are possible at the desired steel embedment [5]. Nair replaced the damaged steel deck of a bridge in Louisiana with a new FRP-wrapped balsa deck. The laboratory proposes and validates two innovative monitoring systems, namely, a fiber Bragg grating (FBG)-based moisture monitoring system and an optical time-domain reflectometer (OTDR)-based interface slip/degumming monitoring system. Nair developed comprehensive experimental testing and live load field testing. It is used to evaluate and continuously monitor the entire service life of new composite systems. Two innovative monitoring systems were proposed and validated in the laboratory, followed by field testing. The purpose is to evaluate the overall structural performance, evaluate the bonded deck-girder interface, and calibrate the numerical model to further study the composite performance between the deck and the girder. Field assessments reveal overall structural performance and help establish a baseline for future condition assessments [6]. Chiniforush studied the long-term behavior of steel and wood composite (STC) beams under continuous loads. Combining 3D diffusion analysis based on finite difference (FD) scheme and 1D fiber unit model to simulate the changes of MC and temperature in the wood cross section due to the change of environmental relative humidity and temperature, the parameter study results show that the creep coefficient of STC beam of 50 years (suitable for various shear connections) is 0.35 [7]. Yang introduced an experimental study of a steel wood composite (STC) connection system consisting of steel H profiles and engineered
wood and adhesive wood produced by larch. A static roll-out test of this new composite connection type is performed to investigate its yield properties and associated failure modes. The results show that the Foschi formula is used to predict the nonlinear load-slip behavior of the considered sample, and the analytical prediction shows a reasonable agreement with the test results [8]. The research of the above scholars has made certain progress in a specific field. But for the steel-wood structure with reinforced layer studied in this paper, it is less involved, so the research in this paper is of pioneering significance and great significance.

The innovation of this paper is that an improved PSO algorithm is proposed, and the steel-wood structure with reinforced layers is tested by using this algorithm. The test method is to test the mechanical properties of two specimens with different numbers of reinforced layers, and the results are comparable and reference value.

2. Mechanical Performance Analysis Model Based on Particle Algorithm

2.1. Particle Algorithm. The PSO algorithm is an intelligent search algorithm derived from simulating the foraging behavior of birds. The PSO algorithm uses the information exchange ability of the population to search for the problem to obtain the optimal solution. The original idea of the PSO algorithm was to simulate a simple social system and study and explain complex social behaviors. But later, particle swarm optimization algorithm was used to solve practical optimization problems, especially it was found that this algorithm can solve engineering optimization problems [9, 10]. A schematic diagram of the particle optimization search is shown in Figure 1.

There are many kinds of research work carried out by the PSO algorithm, which can be classified into the following eight categories: (1) it conducts a theoretical analysis of the PSO algorithm and tries to understand its working mechanism; (2) it changes the structure of the PSO algorithm and tries to obtain an algorithm with better performance; (3) it studies the influence of various parameter configurations on the PSO algorithm; (4) it studies the influence of various topological structures on the PSO algorithm. Particles continuously track individual extremums and global extremums in the solution space to search. Until the specified number of iterations is reached or the specified error standard is met, the flow of the PSO algorithm can be shown in Figure 2. The PSO algorithm is a random, parallel optimization algorithm. Its advantages are as follows: it does not require the optimized function to be differentiable, differentiable, continuous, etc., the convergence speed is fast, the algorithm is simple, and it is easy to program. The disadvantages of the PSO algorithm are as follows. For functions with multiple local extremum points, it is easy to fall into the local extremum points, and the correct result cannot be obtained. There are two reasons for this phenomenon: one is due to the nature of the function to be optimized. The second is due to the rapid disappearance of the diversity of particles in the particle swarm algorithm, resulting in premature convergence. These two factors are often inextricably entangled.

Each particle in the space is represented by its position and velocity, assuming that the position and velocity of the \(i\)-th particle at time \(t\) are represented by sum, and then,

\[
X_i(t) = \{x_1^i(t), x_2^i(t), \ldots, x_D^i(t)\},
\]

\[
V_i(t) = \{v_1^i(t), v_2^i(t), \ldots, v_D^i(t)\},
\]

\[i = \{1, 2, \ldots, N\},\]

where \(N\) is the number of particles.

The particle update method is

\[
V_i(t+1) = \omega(t)V_i(t) + c_1r_1(\text{Pbest}(t) - X_i(t)) + c_2r_2(\text{Gbest}(t) - X_i(t)),
\]

\[
X_i(t+1) = X_i(t) + V_i(t+1).
\]

Among them, \(c_1\) and \(c_2\) are nonnegative constants, also called acceleration factors. \(r_1\) and \(r_2\) are a uniformly distributed random number between \([0, 1]\). is a coefficient to balance the search capability, and

\[
\omega(t) = \omega_{\text{max}} - \frac{\omega_{\text{max}} - \omega_{\text{min}}}{T_{\text{max}}}.
\]

\(\text{Pbest}(t)\) represents the best position of the particle at time \(t\), represents the best position of the partner, and there are

\[
\text{Pbest}_i(t) = \arg\min\{f(X_i(1)), f(X_i(2)), \ldots, f(X_i(t))\},
\]

\[
\text{Gbest}(t) = \arg\min\{f(P\text{best}_1(t)), f(P\text{best}_2(t)), \ldots, f(P\text{best}_N(t))\}.
\]

2.2. Steel-Timber Structure System with Reinforced Layer. The forms of steel-timber structures include one-piece, that is, steel and timber are combined to form the basic components. It is based on the one-piece steel-timber composite structure, the type of concentric diagonal bracing, the layout of common strip-type lattice columns and steel-reinforced lattice columns, and their energy consumption principles. Separation is the separation of timber and steel as components [11, 12].

Figure 3 is a structural diagram of a one-piece steel. The connection method of the beam, the steel bar, and the limb column can be mortise and tenon, planting bar, pin and bolt, screw, steel gusset plate, steel filling plate bolt, steel plytimmer bolt, or other forms of connection. The connection should be firm and reliable, and the force transmission should be simple [13, 14]. The steel and timber structure can be used in some longer sections, one can reduce weight, and two has better ductility and firmness.

At present, steel-timber composite components have been applied. Some examples of steel-timber composite structures are shown in Figure 4. Steel has the highest strength and highest ductility of all building materials. And it is also an isotropic material, which means its properties are constant throughout the material.
But there are also some disadvantages, such as easy rust and easy buckling. On the other hand, the processing of timber is excellent, with a high strength-to-weight ratio. Unlike steel, timber is an anisotropic material. This means that the material has the advantage of being subjected to different orientations and locations under different loads. The steel-timber structure is to make up for their respective shortcomings and improve their performance. Figure 5 shows two common forms of steel-timber combination [15, 16].

Professional connection hardware is made by many manufacturers. The required structural design values are usually determined through testing to obtain the load capacity of professional connectors. Manufacturer’s catalogs usually provide the required values. Consequently, the designer can choose a standard connector based on the design loads determined for a particular node or connection. However, designers should carefully consider the type of fasteners used in the connector. Manufacturers sometimes require or propose the use of patented nails, bolts, or other devices [17, 18].

2.3. Mechanical Properties of Steel-Timber Structure System. The steel-timber structural system has a large lateral stiffness, and generally, no support system can be set up. The steel-timber structure itself is the main lateral force-resistant member of the structural system. In the hybrid steel-timber structure, the compressive buckling of the web members of other joints with stiffened layers can be limited by the shear yielding of the stiffened layers of the open web. The empty section in the middle of the span with the reinforcement layer has the function of energy dissipation. This gives the structure a stable bearing capacity and good seismic performance. When the hybrid steel-timber structure is used, the bending moment of the column end in the structure can also be significantly reduced. For its mixed steel-timber structure, for example, open internodes are set in the midspan with reinforced layer, adjacent to the midspan, and adjacent to the side span. This is not only beneficial for the structure to have good energy consumption performance but also for the setting of walkways in the reinforced layer in office buildings, buildings, and other buildings. Figure 6 shows a common steel-timber structure system [19].

2.3.1. The Stress Characteristics of Various Structural Systems Can Be Obtained Under the Conditions of Different Forms and Combinations of Steel-Timber Mixed Belt Reinforcement Layers

(1) Under the action of vertical load, the closer the empty internode is to the side span, the larger the internode span of the reinforced layer, the greater the midspan deflection of the reinforced layer

(2) The influence of the position of the empty internodes on the midspan deflection of the reinforced layer under vertical load is more obvious than that of the internode span of the reinforced layer

(3) With the increase of the number of internodes of the reinforced layer, the transverse shear-weight ratio
and transverse stiffness of the structural system increase significantly [20].

(4) The position of the empty internodes has a great influence on the interstory displacement of the structural system under the horizontal load. Although the lateral stiffness of the structure is large, the lateral interstory displacement under horizontal load increases significantly because the position of the empty internodes is close to the side spans.

(5) When arranging various forms of mixed belt reinforcement layers in the structural system, there is a certain eccentricity in the structure layout due to the change of the positions of the empty internodes of each belt reinforcement layer. Therefore, there is a certain torsional deformation in the structure, and the torsional mode of the structure appears earlier.

In order to study the applicability of the steel-timber hybrid structural system in different buildings, the height of the reinforced layer is changed in this paper. It selects two other models with different layer heights with reinforcement for calculation. The two models M5 and M6 only change the height of the reinforced layer, and the construction scheme is similar to the standard model M1. The height of the reinforced layer is 2.6 m and 3.0 m, respectively. The specific calculation results are compared as shown in Figure 6.

2.3.2. The Influence of the Number of Reinforced Layers of Different Steel-Timber Structures on the Mechanical Performance of the Steel-Timber Hybrid Structure System with Staggered Reinforced Layers

(1) Under the same vertical load, as the height of the reinforced layer increases, the bending moment of the chord with the reinforced layer and the axial force of the column do not change much. The axial force of the web rod is reduced, and the midspan deflection of each layer with reinforcement is not much different.

(2) The shear weight ratio in the X and Y directions of the structure decreases sequentially with the increase of the height of the reinforced layer. At the same time, the horizontal displacement of each layer increases successively under the earthquake action in the X and Y directions, and the longitudinal and lateral stiffness of the structure decreases significantly.

2.3.3. Influence of Different Aspect Ratios on the Mechanical Properties of Steel-Timber Structural Systems. Under the action of vertical load, the relationship between the mechanical performance of the steel-timber hybrid structure with the reinforced layer, the span of the reinforced layer, and the length-width ratio of the building is as follows:

(1) When the type and span of the reinforced layer are constant, changing the aspect ratio of the building, the axial force of the column, the axial force of the web member, the bending moment of the chord, and the maximum deflection of the reinforced layer in the midspan are similar.

(2) When the longitudinal length of the building is constant, the axial force of the column and the axial
force of the web increase significantly with the increase of the span of the reinforced layer.

(3) The span of the reinforced layer has little effect on the positive and negative bending moments of the chord of the reinforced layer. The pitch of the chord section plays a controlling role in the bending moment of the chord.

(4) With the increase of the span of the reinforced layer, the midspan deflection of the reinforced layer will also increase significantly. This is one of the main
Figure 5: Steel-timber composite structure.

Figure 6: Staggered steel-timber structure system.
factors restricting the application of the staggered reinforced layer structure system in larger depth buildings.

2.3.4. Influence of Mechanical Properties of Steel-Timber Structural Systems with Different Longitudinal Lateral Force Resistance Systems.

In the structural system with stiffened layer, the lateral force is borne by the stiffened layer. The reinforced layer greatly increases the lateral rigidity of the structure and has good lateral force resistance characteristics. The longitudinal stiffness of this system is relatively weak. The longitudinal stiffness of the reinforced layer system is provided only by the frame without bracing or shear walls [21]. Even if the strong axis of the frame column is parallel to the longitudinal direction of the structure (such as connecting the I-section column web to the truss), it is usually difficult for beams and columns with smaller dimensions to meet the longitudinal lateral force resistance requirements. Therefore, in the longitudinal direction of the structure, support or shear walls must be arranged in appropriate positions in combination with the architectural plan [22].

3. Mechanical Test of Steel-Timber Structure System with Reinforced Layer

3.1. Improvement of Particle Swarm Optimization Algorithm Based on Population Diversity.

Most practical application problems contain a large number of objective functions. It is difficult to describe these objective functions with explicit mathematical expressions, and it is even more difficult to solve these problems. In the process of population searching for the optimal solution, due to premature convergence, the population will gradually gather to the local optimum point. In the continuous decision variable space, there is a neighborhood interval near the global optimal point. In the neighborhood interval, the fitness value of the decision variables is inversely proportional to their distance from the global optimum. According to the principle of median value, that is, in the neighborhood area with more good points, the probability of finding a better point is higher. Therefore, in order to find better points, fine search can be performed in the neighborhood containing better points. The POS swarm intelligence algorithm is to imitate the biological behavior of some social animals, such as finding food or water. The whole population is in an orderly process, and there is coordination and consistency among individuals. The behavioral properties of this biological group mainly rely on two biological instincts: intuition and maneuver [23, 24].

Intuition is the ability of biological individuals to evaluate and judge the search space. It relies on the previous

<p>| Table 1: Mechanical properties of timber. |</p>
<table>
<thead>
<tr>
<th>Mechanical parameters</th>
<th>Numerical value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (g/cm^3)</td>
<td>0.71</td>
</tr>
<tr>
<td>Grain compressive strength (N/mm^2)</td>
<td>53.20</td>
</tr>
<tr>
<td>Flexural strength along grain (N/mm^2)</td>
<td>121.10</td>
</tr>
<tr>
<td>Grain tensile strength (N/mm^2)</td>
<td>117.40</td>
</tr>
<tr>
<td>Along-grain shear radial strength (N/mm^2)</td>
<td>8.33</td>
</tr>
<tr>
<td>Along-grain shear chord strength (N/mm^2)</td>
<td>6.80</td>
</tr>
<tr>
<td>Compression elastic modulus along grain (N/mm^2)</td>
<td>13120.00</td>
</tr>
<tr>
<td>Poisson’s ratio</td>
<td>0.49</td>
</tr>
</tbody>
</table>

<p>| Table 2: Mechanical properties of bolts. |</p>
<table>
<thead>
<tr>
<th>Mechanical parameters</th>
<th>Numerical value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield strength (N/mm^2)</td>
<td>940.00</td>
</tr>
<tr>
<td>Yield strain (%)</td>
<td>0.456</td>
</tr>
<tr>
<td>Ultimate strength (N/mm^2)</td>
<td>1130.00</td>
</tr>
<tr>
<td>Ultimate strain (%)</td>
<td>10.00</td>
</tr>
</tbody>
</table>

<p>| Table 3: Mechanical properties of smooth round steel bars. |</p>
<table>
<thead>
<tr>
<th>Mechanical parameters</th>
<th>Test measurement average value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield strength (N/mm^2)</td>
<td>383.2</td>
</tr>
<tr>
<td>Ultimate strength (N/mm^2)</td>
<td>503.1</td>
</tr>
<tr>
<td>Elastic modulus (N/mm^2)</td>
<td>2.01 × 10^5</td>
</tr>
</tbody>
</table>

<p>| Table 4: Mechanical properties of steel. |</p>
<table>
<thead>
<tr>
<th>Mechanical parameters</th>
<th>Test measurement average value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield strength (N/mm^2)</td>
<td>283.4</td>
</tr>
<tr>
<td>Ultimate strength (N/mm^2)</td>
<td>453.9</td>
</tr>
<tr>
<td>Elastic modulus (N/mm^2)</td>
<td>1.99 × 10^5</td>
</tr>
</tbody>
</table>

Figure 7: Reinforcing layer construction drawing.
experience and the mutation ability after the accumulation of experience, that is, experience provides judgment reference. But it does not act as a mandatory constraint or rule. This ensures that different individuals in the group search different areas. Maneuvering is the way to obtain the final goal, and it is a specific decision-making process guided by intuition. The individual has two maneuvering modes: a global-wide large-step search and a small-step survey within a local neighborhood.

This paper proposes a POS algorithm based on population diversity, which is referred to as PSODM algorithm. It mimics the behavior of a biological random search. The random search behavior is realized by memory, experience, uncertainty, and mutual communication between individuals. In the optimization process of the algorithm, the particles will focus (or follow) the current optimal individual and randomly optimize together with the optimal individual’s neighborhood group. In this algorithm, the intuition of particles is reflected in the delineation of individual exploration areas. In the search area, the individual can search for optimization from any direction, and its behavior is not constrained. Different from the search in the standard PSO algorithm, the two maneuvering modes of the PSODM algorithm are determined by the individual without strict restrictions.

The PSODM algorithm introduces a weight factor $K$, and its algorithm model is

$$V_i(t+1) = K[V_i(t) + c_1 r_1(P_{\text{best}}(t) - X_i(t)) + c_2 r_2(G_{\text{best}}(t) - X_i(t))],$$

(9)

where $r_1$ and $r_2$ are random numbers. The PSODM algorithm introduces a weight factor $K$, and its algorithm model is

$$K = \frac{2k}{2 - \varphi - \sqrt{\varphi^2 - 4\varphi}},$$

(10)

$$X_i(t+1) = X_i(t) + \omega(t) V_i(t) + \phi_1(P_{\text{best}}(t) - X_i(t)) + \phi_2(G_{\text{best}}(t) - X_i(t)),$$

(11)

where $\phi_1 = c_1 r_1$, and $\phi_2 = c_2 r_2$. It can be expanded according to formula (10):

$$X_i(t+1) = (1 - \phi_1 - \phi_2) X_i(t) + \omega(t) V_i(t) + \phi_1 P_{\text{best}}(t) + \phi_2 G_{\text{best}}(t).$$

(14)

It can be obtained according to the initial conditions $x(0)$ and $x(1)$:

$$X_i(t) = k_1 + k_2 \alpha' + k_3 \beta_1,$$

(15)

where $k_1 = \frac{\phi_1 P_{\text{best}}(t) + \phi_2 G_{\text{best}}(t)}{\phi_1 + \phi_2}$, \(\alpha' = \frac{1 + \omega - \phi_1 - \phi_2 + \gamma}{2}\), \(\beta_1 = \frac{1 + \omega - \phi_1 - \phi_2 - \gamma}{2}\), and \(\gamma = \sqrt{(1 + \omega - \phi_1 - \phi_2)^2 - 4\omega}\).

(16) and (17)

(18) and (19)

The solving equations for the initial elastic modulus $K$, modulus parameter $n$, and destruction ratio in statics are as follows:

$$\log \frac{E_i}{P_a} = \log k + n \log \left(\frac{\sigma_3}{P_a}\right),$$

(20)

where the intercept of the fitted line is $a$, the slope is $b$, and $E_i$ is the initial modulus.

The volume deformation parameter is solved as follows:

$$B = \frac{\sigma_1 - \sigma_3}{3\varepsilon_v},$$

(21)

$$B = K_4 P_a \left(\frac{\sigma_3}{P_a}\right)^m.$$
Figure 9: Graph of cumulative energy consumption and displacement.
In the formula, the body variable elastic modulus is $K_b$, and the body variable modulus parameter is $m$.

3.2. Static Test of Steel-Timber Structure with Reinforced Layer.

(1) Selection of test materials: it selects two steel and timber specimens with different reinforcement layers, A and B. The number of reinforcement layers of the A specimen is twice that of the B specimen. The steel-timber composite structural specimens are divided into Q-shaped steel, H-shaped round steel bar, 10.9 grade bolts, and pine timber. The mechanical properties of these materials are shown in Tables 1–4.

(2) Test of specimen: in the quasistatic test, two 50-ton sensors are used to apply vertical force, and a 100-ton horizontal actuator is used to apply repeated displacement to the free end of the top beam, and the horizontal load at the beam end is collected by an automatic data collector. It makes the horizontal actuator positive when applying thrust, negative when applying pulling force, and applies load and horizontal displacement to the specimen. The reinforcing layer construction drawing is shown in Figure 7.

3.3. Experimental Results. According to the above test, the stagnation curves of the two specimens A and B were obtained, as shown in Figure 8. The stagnation curve is also called the restoring force characteristic curve, which is the curve of the restoring force changing with the deformation. In the seismic analysis of the structure, the restoring force model is the basis for the seismic analysis. It mostly adopts the quasistatic test (also known as repeated static load test) method to determine the restoring force characteristic curve.

It can be seen from Figure 8 that the stagnation amplitude of the A specimen with more reinforcement layers is significantly smaller than that of the B specimen. The stagnation amplitude of the B specimen is about twice that of the A specimen, indicating that the bearing capacity of the A specimen is better. That is to say, the more layers with reinforcement, the better the bearing capacity.

In addition, the relationship between cumulative energy consumption and displacement is calculated in this paper, as shown in Figure 9.

It can be seen from Figure 9 that for the A specimen with more reinforced layers, the cumulative energy consumption is relatively higher. Among them, the average displacement of A specimen is 4.6 kN-mm more than that of B specimen in the displacement of 1 mm. This correlates with the test results of the stagnation curve. The smaller the magnitude of the stagnation curve, the greater its energy consumption capacity.
Finally, the ultimate shape deformation test of the specimen was carried out, and the results shown in Figure 10 were obtained.

It can be seen from Figure 10 that the shape deformation parameters of A specimen are larger by 0.24 m. This shows that the higher the ultimate fatigue strength, the stronger the bearing capacity and the better the stability.

4. Discussion

In this paper, PSO and quasistatic test research are carried out on the mechanical properties of steel-timber composite column specimens with different forms of reinforcement layers of two groups of steel bar trims.

The PSO algorithm is a new evolutionary algorithm based on swarm intelligence. Its research has just begun, and it has not formed a systematic analysis method and a certain mathematical foundation like the genetic algorithm and simulated annealing algorithm. There are many problems that need further research.

(1) Scope of application: the most successful application of the PSO algorithm is in the evolutionary neural network, and many other applications are still in the research stage. Obviously, the PSO algorithm will not be limited to these current fields. If the PSO algorithm is introduced into the fields of machine learning and automatic control, it will greatly promote the research and development of the algorithm

(2) Selection and design of parameters: the choice of parameters in the PSO algorithm depends on the specific problem, and it takes many experiments to design suitable parameters. Research on how to select and design parameters to reduce the dependence on specific problems will also greatly promote the development and application of the PSO algorithm

5. Conclusion

This paper firstly summarizes the research purpose and content of this paper in Abstract. It introduces the background meaning of this article and some key contents in Introduction. Secondly, some scholars’ research results on the main content of this paper are listed in the relevant work part, so as to understand the research status of steel-timber structures with reinforced layers.

In the theoretical research part, this paper firstly introduces the particle algorithm, including its concept, process, and mathematical model. It introduces the control parameters of the particle swarm optimization algorithm, as well as the basic test functions and evaluation criteria for evaluating the performance of the particle swarm optimization algorithm. Secondly, through systematic experiments and analysis, it proposes the value strategy of the main control parameters of the particle swarm optimization algorithm. It then introduced the steel-timber structure system with reinforced layers, including the form of its steel-timber structure and its related contents. Finally, the mechanical properties of the steel-timber structure system are analyzed. It analyzes the stress characteristics of various structural systems under the conditions of different forms and combinations of steel-timber mixed belt reinforcement layers.

In the experimental test, the improvement of the particle swarm optimization algorithm based on population diversity is carried out first, and then, the static test is carried out on the steel-timber structure with reinforced layer. The experimental results show that for the steel-timber structure with reinforced layers, the more reinforced layers, the better the bearing capacity. The smaller the amplitude of the stagnation curve, the greater the energy consumption capacity, the greater the damping coefficient, and the better the stability.

Data Availability

This article does not cover data research. No data were used to support this study.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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