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RESEARCH ON MODELING AND OPTIMIZATION PROGRAM OF LONG-SPAN HYBRID GRID HANGAR BASED ON LEVERAGE PRINCIPLE

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ABSTRACT

A long-span hybrid grid hangar structure and a modeling method for the long-span hybrid grid hangar structure based on the principle of leverage are proposed in this paper. Based on the SAP2000 spatial structure design software, the C# language was used to develop a plug-in to automatically create a long-span hybrid grid structure based on the principle of leverage, which realized the automatic generation by inputting parameters such as the span of the hangar structure, the number of horizontal grids, and the number of vertical grids. The optimization design method of the long-span hybrid grid structure based on particle swarm algorithm is proposed. SAP2000 software is used and the *C#* language is used to develop the optimization design program of the long-span hybrid grid structure based on the principle of leverage. The optimization design is carried out, and the optimization results show that the program can reduce the thickness of the roof and reduce the vertical displacement at the opening of the hangar roof on the basis of meeting the current specifications.

KEYWORDS

Hangar structure, Leverage, SAP2000, Optimization design

INTRODUCTION

As China continues to develop into a strong civil aviation country, more and more long aircraft are put into use [1-2]. The maintenance and storage requirements of long aircraft make the design of hangar continuously improve the requirements for span and net height. The hangar is located near the airport and the design elevation of the hangar roof structure is limited by the airport net requirements, so the hangar needs to leave as much net height as possible to meet the maintenance needs. Therefore, this requires the thickness of the hangar roof structure to be as small as possible [3]. To meet the entry and exit requirements of long aircraft, the opening side of the hangar cannot be equipped with a column, so the roof structure of the hangar has only three sides support. Thus, the roof structure of the hangar should have greater rigidity, so that the vertical displacement on the side of the opening meets the requirements of the design specifications. In recent years, the space structure has developed rapidly, and various grid structures, tensile structures, and thin shell structures have been widely used in long-span structural engineering. As a result, a series of special design requirements have been developed for the hangar roof. When the long-span hangar adopts a typical spatial structure, a special design is required on the side of the door to meet the specification requirements [4]. However, such a design often affects the net height of the hangar. At the same time, as the span of the hangar increases, the design difficulty is also increasing [5]. Therefore, in order to adapt to the current long aircraft size, storage requirements and the particularity of the long opening structure, this paper puts forward a new form of aircraft hangar with better structural safety, economy and technical effect, which is of great significance to the development of civil aviation in our country. The parametric modelling of long-span hybrid grid hangar structure based on lever principle is a complex process. The grid structure is composed of joints and members, and the number of model components is usually huge. Even small-scale grid projects contain hundreds of grid joints and members [6]. The size of the joints and the type of the members in the actual project are not regular, so it is almost difficult to complete by conventional manual modelling. In the structural calculation software of space grid, the space grid model is generated automatically. Similarly, the plug-in for automatic creation of space grid can be written on SAP2000 by means of secondary development.

At present, current space grid structure design software can realize the optimization of the member section of the grid structure, but there is no mature technical support for the optimization method of the grid thickness. Only the specifications and the recommended values provided by the grid design manual [7]. For safety considerations, designers need to establish multiple groups of croupalculation models and adjust parameters to optimize design. In the whole optimization design process, some outstanding problems will inevitably appear, such as complex calculations, low work efficiency, and waste of time. Especially for the hangar structure, it is necessary to provide as much internal space as possible for the aircraft in addition to meeting the net requirements of the airport building [8]. Thus, we must optimize the design, while meeting the normal use requirements, the hangar roof structure should be as thin as possible, and the vertical displacement of the hangar structure with long opening should be as small as possible.

GEOMETRICAL CONSTRUCTION OF THE STRUCTURE

The long-span hangar structure has its particularity, which must require the boundary conditions of three sides to support and the other side to be free. In order to facilitate the freedom of aircraft entry and exit, only one column can be set at the opening, as shown in Figure 1. Due to the particularity of the hangar structure, if the opening is not specially treated, it will have greater vertical displacement, as shown in Figure 2. Therefore, reducing the vertical displacement on the side of the opening to meet the design specifications is the key to the design of the hangar roof structure.

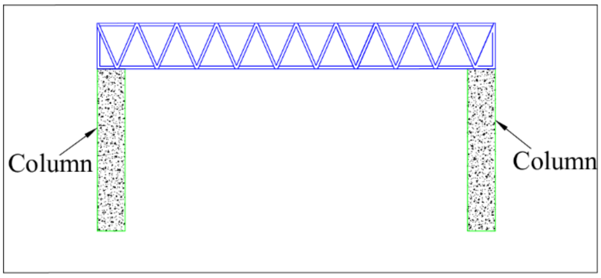

Fig. 1 – Elevation of the hangar

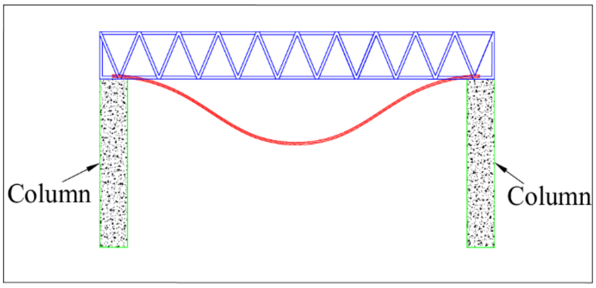

Fig. 2 – Elevation of the hangar without special treatment

In order to solve the problem of vertical displacement at the opening of the hangar, considering the balance condition, the lever principle is applied to the long-span hangar structure. Move the hangar structure support inward and adopt the support as the fulcrum of the lever. After that, set cables at the left and right cantilever ends to anchor the cables vertically to the ground. As shown in Figure 3, the connection between the column and the upper grid serves as a fulcrum, and the left and right sides are equivalent to two levers. The levers can improve the bearing capacity of the hangar roof to ensure the stability and safety of the hangar structure.

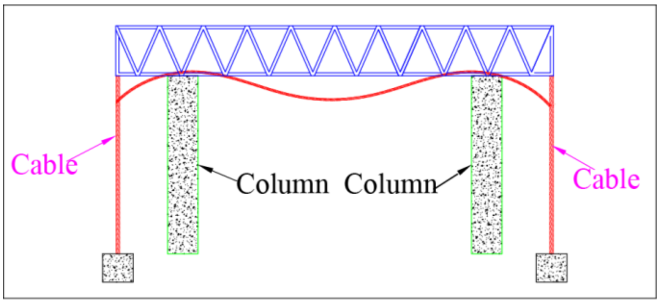

Fig. 3 – Elevation of the hangar based on the principle of leverage

Based on the above ideas, 3D3S space structure design software is used to establish a geometric model of a long-span hybrid grid hangar based on the principle of leverage, as shown in Figure 4.

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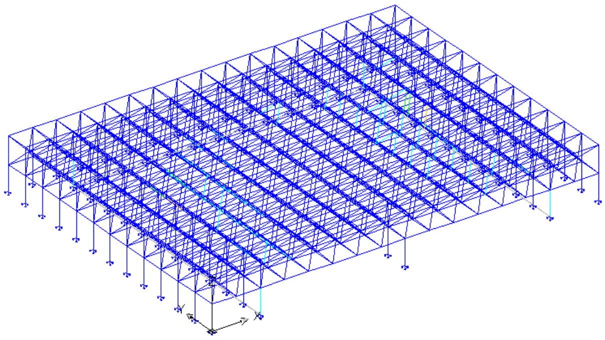

Fig. 4 – Hangar model based on the principle of leverage

STRUCTURAL MODELING PROGRAM

In this paper, the internal call method is used to write the SAP app plug-in and run it in the menu bar of SAP2000 [9-10]. The plug-in development environment uses C# VS2013, .NetFramework4.5, builds a class library project [11-12]. And add a reference to SAP2000.exe, and puts the compiled plug-in into the menu bar of SAP2000 V20 to run. The plug-in interface written in this article is shown in Figure 5.

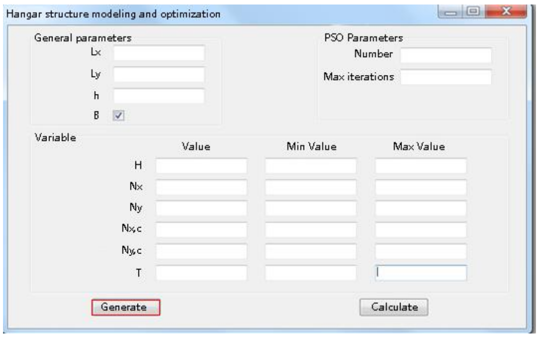

Fig. 5 – Development interface of structural modeling program

Parametric modelling process

First, the key parameters are inputted, and modelling parameters are mainly divided into general attribute parameters and grid variable parameters. In this paper, the large-span hangar spans from the centre to the left and right column as area 2 the general parameters include grid length, width, column top height h and whether the edge is cabled or not B. The grid variable parameters include grid height H, x-direction grid number, y-direction grid number, x-direction column distance to the edge position $N_{x,c}$, y-direction column distance to the edge position $N_{y,c}$, cable cooling T (simulated cable force), and the variation norm of each parameter.

The SAP2000 model generated after the input parameters is initialized, and the inverted triangular cone is selected as the basic unit of the space grid. The hangar roof adopts steel circular hollow sections, and four kinds of steel circular hollow sections of the upper, middle, lower and oblique web of the space grid are defined. The upper chord joints, the middle chord joints and the lower chord joints of the grid are established in turn, the column joints and the cable joints are established, and the names of the joints are recorded respectively. Finally, the grid element model is established according to the parameters and joints, and the upper chord, middle chord, lower chord, web, column and vertical cable are established according to the grid joints.

Constraints are imposed on the hangar model generated above, and constraints are imposed on the bottom of the column and the bottom of the vertical cable to ensure that the cable and column maintain a rigid connection with the ground. Increase load conditions such as constant load, live load, temperature, etc., apply the above-mentioned load conversion joint load to the corresponding joint, use the cooling method to apply prestress to the cable, and consider increasing the limit state of normal use.

```
Sap.eCNameType tempeCNameType = Sap.eCNameType.LoadCase;
//combination
ret = SapModel.RespCombo.Add("COMB1", 1);

ret = SapModel.RespCombo.SetCaseList("COMB1", ref tempeCNameType, "dead1", 1.0);

ret = SapModel.RespCombo.SetCaseList("COMB1", ref tempeCNameType, "live2", 1.0);

ret = SapModel.RespCombo.SetCaseList("COMB1", ref tempeCNameType, "temp3", 1.0);

}
```

Example

This section uses the long-span hybrid grid hangar program plug-in developed above based on the lever principle to call the SAP2000 spatial structure design software to establish a long-span hybrid grid hangar model based on the lever principle. The input modeling parameters as shown in Table 1.

Tab. 1 - Parameters of Hangar Model

Parameter name	Parameter value
x/m	120
y/m	60
h/m	20
Grid height /m	5
N_x	40
N_y	20
$N_{x,c}$	4
$N_{y,c}$	2
T/℃	-30

Input the parameters in Table 1 into the parameter input dialog box of Figure 5 for parametric modeling of the hangar. Click [Generate], the compiled plug-in sapAPP can call the SAP2000 spatial structure design software to automatically generate the hangar mode. The hangar model initialization is shown in Figure 6, and the generated hangar model is shown in Figure 7.

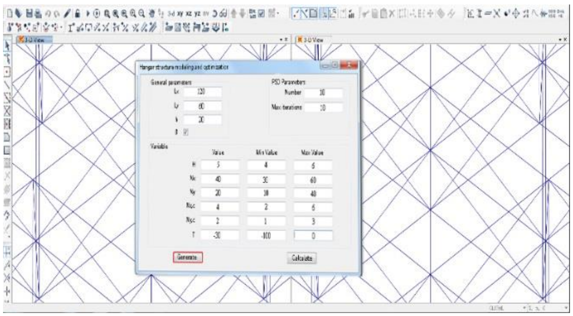

Fig. 6 – Hangar model initialization interface

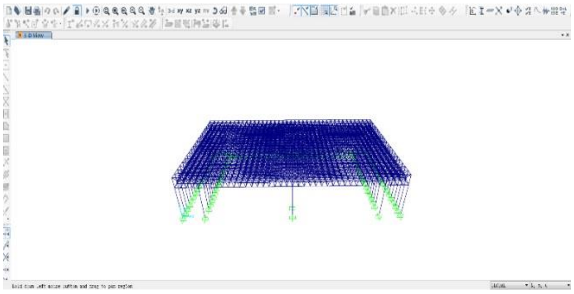

Fig. 7 – Automatic generation of hangar model

OPTIMIZATION DESIGN OF HANGAR STRUCTURE BASED ON PARTICLE SWARM OPTIMIZATION

Establishment of optimization model

Before optimizing the long-span hybrid grid hangar structure based on lever principle, it is necessary to determine the optimization model parameters, constraint conditions and objective function.

Given the length, width, height, material, section and other key parameters of the grid, the optimization model is as follows:

$$H = f\left(N_x, N_y, N_{x,c}, N_{y,c}, B, T\right) \tag{1}$$

$$U_{z1} \le \frac{L_1}{250} \tag{2}$$

$$U_{z2} \le \frac{L_2}{125} \tag{3}$$

$$N_x \in (10,50) \tag{4}$$

$$N_y \in (10,50) \tag{5}$$

$$N_{x,c} \in (1,10) \tag{6}$$

$$N_{y,c} \in (1,10) \tag{7}$$

$$B \in (0,1) \tag{8}$$

$$T \in (-100,0) \tag{9}$$

H —Grid thickness；

N_x —Number of grids in *x* direction；

N_y —Number of grids in *y* direction；

$N_{x,c}$ —The number of grid from the edge of the column in the *x* direction ；

$N_{y,c}$ —The number of grid from the edge of the column in the *y* direction ；

B —Prestressed cable；

T —Cable cooling temperature；

U_{z1}—Vertical displacement of area 1；

L_1— Area 1 span；

U_{z2}—Vertical displacement of area 2；

L_2—Area 2 span;

The objective function of the particle swarm is obtained by parametric modeling and calculation of the SAP2000 model. Under the premise of ensuring the minimum deflection of the hangar roof, the minimum thickness of the grid roof is the goal, that is, the multi-objective function is as follows:

$$Y\left(h_{\min}, U_{z1\min}, U_{z2\min}\right) = h + \frac{U_{z1}}{L_1} + \frac{U_{z2}}{L_2} \tag{10}$$

The particle in this paper refers to the key parameters of the grid, and the corresponding target value of the particle is the target value in the above optimization model.

Optimization design program development

This program is written by Microsoft Visual Studio 2013 software C # language [13-14]. According to the above parametric modeling, particle swarm optimization algorithm [15] is used to optimize the structure of long-span hybrid grid hangar. The interface of the hangar structure optimization software is shown in Figure 5. The optimization program includes 6 main modules: input the key parameters of the particle swarm, initialize the particle swarm, iterate the particle swarm, update the particle swarm, end the iteration, and output the result.

The first module inputs the key parameters of the particle swarm. The key parameters of the program are the key parameters of the grid and the number of particles, the maximum number of iterations and so on. In the PSO algorithm, the learning factors c_1 and c_2 determine the experience of the particle itself and the group. Setting smaller or longer c_1 and c_2 is not conducive to the search of particles. This section sets the learning factor $c_1=c_2=0.9$. In this paper, the long-span hybrid grid hangar structure based on the lever principle will be used to search for area 1 and 2 locally using the particle swarm algorithm, so the inertia weight w is set to 0.2.

```
public class cLiZiParam
  {
    // Whether to calculate multiple times Calculate parameters every time
    public int N = 10;// Number of particles
    public int maxIteration = 10;// Maximum iterations times
    public int keepNum = 5;// If no better solution is found for num times, exit
    // No assignment required for calculation
    public double c1 = 0.9;// c1
    public double c2 = 0.9;// c2
    public double w_max = 0.2;//w
    public double w_min = 0.2;//w
```

The second module randomly initializes each particle according to the key parameters. The particles can be initialized randomly by inputting the key parameters of grid modeling, the number of particles and the number of iterations. The third module, particle swarm iteration, is iteratively calculated by the particle swarm method to calculate the fitness value of each particle. If the fitness value is better than the current individual extreme value of the particle, set P_i to the position of the particle and update the individual extreme value in time. If the optimal particle in the individual extreme value of all particles is better than the global extreme value searched at present, the position of the particle is set to P_g ,and enter the global extreme value and sequence number update of the fourth module. The fourth module updates the particle swarm, checks the range of all parameters, and updates the speed and position of each particle. At the end of the iteration of the fifth module, check whether it meets the end basis. The sixth module outputs the results and all the parameter values of the global optimal solution. The results can also be extracted from the result.txt file under the working path, and the roof thickness and the minimum displacement of hangar roof area 1, that is, zone 1 deflection, can be extracted from the hangar optimization results.

```
void show_Result()
    {
      string message = " Result:";
      progressBarGo.show(message);
      message = "Optimal solution：" + pg.obj.ToString("0.0000");
      progressBarGo.show(message);
      message = "H：" + pg.mHz.ToString("0.0000");
      progressBarGo.show(message);
      message = "Nx：" + pg.mGridNum_x.ToString();
      progressBarGo.show(message);
```

```
            message = "Ny：" + pg.mGridNum_y.ToString();
            progressBarGo.show(message);
            message = "Nx,c：" + pg.mSupportPosIth_x.ToString();
            progressBarGo.show(message);
            message = "Ny,c：" + pg.mSupportPosIth_y.ToString();
            progressBarGo.show(message);
            message = "T：" + pg.mTemperature.ToString("0.0000");
            progressBarGo.show(message);
            message = "Umin1：" + pg.minDis_1.ToString("0.0000");
            progressBarGo.show(message);
            message = "Umax1：" + pg.maxDis_1.ToString("0.0000");
            progressBarGo.show(message);
            message = "Umin2：" + pg.minDis_2.ToString("0.0000");
            progressBarGo.show(message);
            message = "Umax2：" + pg.maxDis_2.ToString("0.0000");
            progressBarGo.show(message);
        }
        #endregion
    }
}
```

The extraction interface is shown in Figure 8. Repeating the above 6 modules can realize the optimization design analysis of the long-span hybrid grid hangar structure based on the particle swarm optimization algorithm.

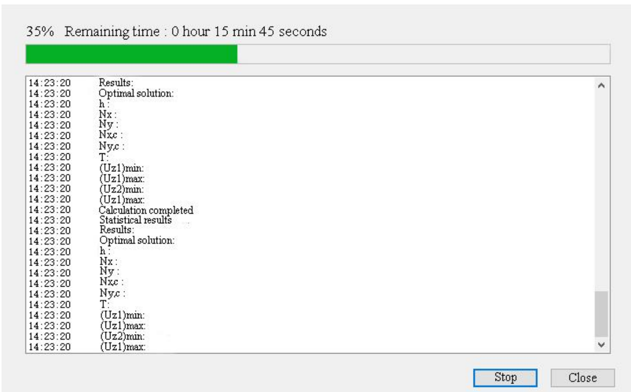

Fig. 8 – Calculation result extraction interface

The optimization program comprehensively considers the displacement of the hangar roof, the number of horizontal and longitudinal grids, the location of hangar supports, the setting of vertical cables and the simulation of cable force by cooling method, which ensures the safety and economy of the optimized long-span hangar structure.

Example

The initial thickness of the grid is 5m, and the height of the column is 15m. The grid number in *x* direction is 40, the grid number in *y* direction is 20, the temperature drop of vertical cable is-30 °C, the grid number of column in *x* direction is 4, and the grid number of column in y direction is 2. The number of particles is set to 10, and the maximum number of iterations is set to 20 times. Taking the above basic parameters as the initial parameters of the model, the hangar structure optimization design program developed in this paper is used to optimize the automatically generated hangar structure.

The optimization result is shown in Figure 9.

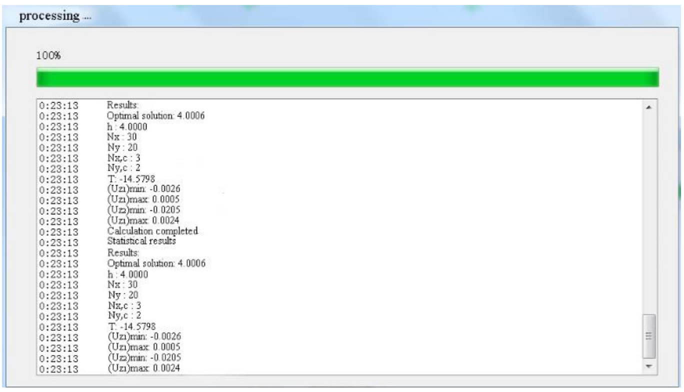

Fig. 9 – Optimized the hangar structure

Sort out the results of the progress bar display in the process of optimization as shown in Table 2.

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Tab. 2 - Optimization results

Iterations	1	2	3	4	5	6	7	8	9	10
H/m	4.57	4.42	4.41	4.39	4.35	4.29	4.14	4.10	4.02	4.00
U_{z1}/mm	6.70	5.60	5.30	5.10	4.60	4.50	4.50	3.40	3.10	2.60
U_{z2} /mm	13.8	17.5	18.4	18.03	19.30	19.60	20.40.	20.40	20.50	20.50
N_x	36	34	32	32	32	32	32	30	30	30
N_y	24	26	22	20	20	19	19	20	20	20
$N_{x,c}$	3	3	3	3	3	3	3	3	3	3
$N_{y,c}$	2	2	2	2	2	2	2	2	2	2
T /℃	-40.58	-36.25	-31.54	-28.47	-26.55	-26.31	-26.31	-24.14	-20.82	-20.82
Iterations	11	12	13	14	15	16	17	18	19	20
H/m	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
U_{z1}/mm	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60
U_{z2} /mm	20.50	20.50	20.50	20.50	20.50	20.50	20.50	20.50	20.50	20.50
N_x	30	30	30	30	30	30	30	30	30	30
N_y	20	20	20	20	20	20	20	20	20	20
$N_{x,c}$	3	3	3	3	3	3	3	3	3	3
$N_{y,c}$	2	2	2	2	2	2	2	2	2	2
T /℃	-14.98	-14.98	-14.98	-14.98	-14.98	-14.98	-14.98	-14.98	-14.98	-14.98

The optimization design of the hangar roof in this paper is to meet the normal use requirements of the hangar, while the hangar roof structure should be as thin as possible, and the vertical displacement of the long opening of the hangar structure should be as small as possible. The thickness of the cover and the vertical displacement of area 1 of the hangar roof are the two most critical optimization indicators. According to the data obtained from the optimization results in Table 2, the variation curve is drawn with the number of iterations as the Abscissa and the roof thickness as the vertical coordinate as shown in Figure 10. The variation curve is drawn with the vertical displacement of the hangar roof structure area 1 and area 2 as the vertical coordinate as shown in Figure 11.

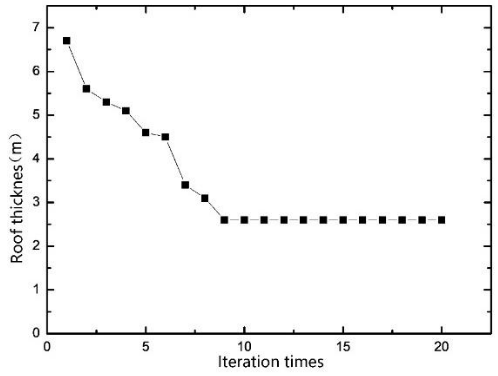

Fig. 10 – The relationship between the roof thickness and iteration times

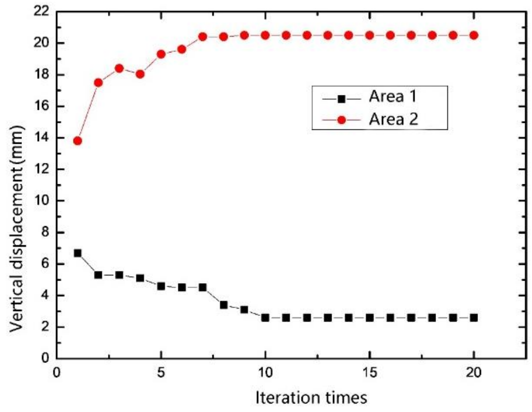

Fig. 11 – The relationship between the vertical displacement and the iteration times

It can be seen from Figures 10 and 11, that as the optimization program iteratively progresses, the hangar roof is gradually reduced, and the optimized target value is adjusted accordingly. With the optimization process of hangar roof area 1, the vertical displacement in the middle span of hangar roof is getting smaller and smaller. The results show that the developed program achieves the purpose of hangar structure optimization design. On the basis of the requirements of the current code, the thickness of the roof and the vertical displacement at the opening of the hangar roof are reduced in this program. The amount of steel used in the grid structure are reduced and the design efficiency are improved.

CONCLUSION

(1) This paper proposes a long-span hybrid grid hangar structure based on the principle of leverage and proposes a modeling method for the long-span hybrid grid hangar structure based on the principle of leverage. This structure can better solve the current problem of vertical displacement at the opening of the hangar.

(2) Based on the SAP2000 spatial structure design software, the C# language was used to develop a plug-in to automatically create hangar structure, which realized the automatic generation by inputting parameters such as the span of the hangar structure, the number of horizontal grids, and the number of vertical grids.

(3) The optimization design method of the long-span hybrid grid structure based on particle swarm algorithm is proposed. SAP2000 software and the C# language are used to develop the optimization design program of the hangar structure. The optimization design is carried out, and the optimization results show that the program can reduce roof thickness and the vertical displacement at the opening of the hangar roof.

(4) In this paper, the optimization program is analyzed and verified by a calculation example. The change of roof thickness and roof displacement with the number of iterations are analyzed separately. The optimization method can have a certain guiding impact for the optimization design of the future long-span space structure hangar.

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