# Optimum design of variable section of portal frame

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## Abstract

**through the portal frame design and optimization of large cross section investigation on the related literature, a comprehensive exposition of the portal frame section optimization design in China's development status and several commonly used domestic portal frame optimization method: optimal criterion, bionics method, mathematical programming method, are presented the representative analysis tool, the optimization principle, different methods and process optimization shortcomings.**

## Keywords

**Portal frame; optimal design; optimal criterion; bionics; mathematical programming.**

## 1. Introduction

Light portal frame is a widely used steel structure. It has the advantages of light weight, short construction period, strong seismic resistance[1], recyclable, environmental protection, energy saving and so on. How to ensure the structural design requirements in the design, but also to achieve the minimum amount of steel, to ensure economic, has become a problem that designers must face. The traditional structural design actually refers to the structural analysis check, that is, first by experience and judgment to make a design, and then in accordance with the traditional theory and methods of its strength, stiffness and stability of the analysis and calculation to see whether to meet the design Constraints, but to get the most reasonable design is very difficult [2 ~ 3]. With the implementation of "Regulations" technology of steel structure of light-weight buildings with gabled frames[4], there are some domestic portal frame optimization software and methods[5], such as optimal criterion, bionics method, mathematical programming method [6], to boost the development of the portal frame.

## 2. Development of portal frame at home and abroad

As the light-weight structure of portal frame has the advantages that other structural systems do not have, and the economic benefits are remarkable, this kind of structure has been widely applied abroad. The light-weight structure of portal frames began in the United states. The light structure system of Japanese and European portal frame is also used more and more, but the American portal frame light structure system develops the fastest and is the most widely used. Light steel structure developed earlier abroad. Because of the development of automobile industry, gabled frames were originally used to build simple houses such as garages. During the two World War, due to the needs of the war, some light and convenient structural steelwork were used in barracks and warehouses. Since 1960s, foreign construction steel has developed rapidly and has made great breakthroughs in its research. At present, most foreign light steel companies have their own portal frame light steel structure system. According to statistics, the United States and Europe by the light steel structure system of nonresidential single storey building accounted for more than 50% of the total, Japan's new 1 to 4 buildings mostly light steel structure [7]. In many countries, such as Britain, America, Japan and Australia, light steel structure has been sold as an economic and efficient building structure system in the form of goods.

China's portal frame structure started late, is the introduction of foreign related materials, technology and software developed on the basis of. In the early 1960s, we studied the welded portal frame structures with I-shaped cross section. However, due to the shortage of steel and funds in our country at that time, the policy of limiting the use of building steel structure, therefore, the portal frame structure system has not been greatly developed. In recent years, with the increase in China's steel production and H steel welding, mass production of cold-formed steel, steel plate, special-shaped steel, especially the promulgation and implementation of "technical specification for steel structure of portal frame light house", the light-weight structure of portal frames has been widely used. But according to the steel structure design code of our country, the design of the portal frame factory building, its cost is about 20% higher than abroad [8]. Therefore, it is very important to reduce the production cost of steel structure of light house in our country.

## 3. Several methods of portal frame optimization are commonly used in China

### 3.1 Best criteria method

From the point of view of engineering, various constraint criteria that the structure should meet when designing are put forward, and the solutions satisfying these constraints are obtained by iterative method. The main feature of the method is fast convergence, the number of reanalysis is not directly related to the book of design variables, and the calculation is not large. But there are limitations that it is mainly applicable to the layout and geometry of the structure. The simplest criteria are the synchronous failure criterion method and the full stress criterion method [9].

In order to better understand the optimal criterion method, the author selects the ANSYS software [10], which is represented by the full stress criterion method, to explain the application in the portal frame.

#### 3.1.1 Uses APDL software in ANSYS to optimize portal frame design

Using ANSYS optimization toolbox for portal frame optimization design, the implementation of the algorithm is a series of analysis, evaluation and correction of the cycle process. This cycle is repeated until all the constraints are satisfied. Using the APDL program language and macro technology to organize and manage the finite element commands of ANSYS, the whole process of parametric finite element analysis can be realized. In the parametric finite element analysis, the parameters can be modified, and the design scheme of various sizes and loads can be analyzed repeatedly. The analysis efficiency is improved and the analysis cost is reduced by [11].

APDL is powerful, but macros written entirely in APDL still have the following problems [12]: 1.APDL language is difficult to control the process of the program, it is difficult to write clear structure of the program. 2. APDL interaction is not smooth enough.

In order to solve the above problems, Qiu Dongrui, Dong Hongying and Xue Xiang [12] have developed ANSYS for the two time. By using the software development environment provided by APDL, a APDL program for single span variable cross-section portal frame optimization design is developed. Through VB human-computer interaction results post-processing interface, extract the results of the calculation data, compare the objective function before and after optimization, design variables, the number of state variables, and get the conclusion that the structure design is reasonable.

A typical ANSYS optimization process requires the following steps to complete the [13], as shown in figure 1.

### 3.2 Bionics

Bionics is a method of searching for the best solution from the point of view of biological evolution of nature, searching for laws, and simulating by logical and mathematical methods. At present, the evolutionary algorithms in nature have simulated the nature process algorithm and imitated the natural structure algorithm, mainly including: evolutionary algorithm (EA), simulated annealing (SA), artificial neural network algorithm (ANN). Evolutionary algorithms mainly include genetic algorithm (GA), genetic programming (GP), evolutionary strategy (ES), evolutionary programming (EP),

among which genetic algorithm [14] is the most representative in the optimization of portal steel frames.

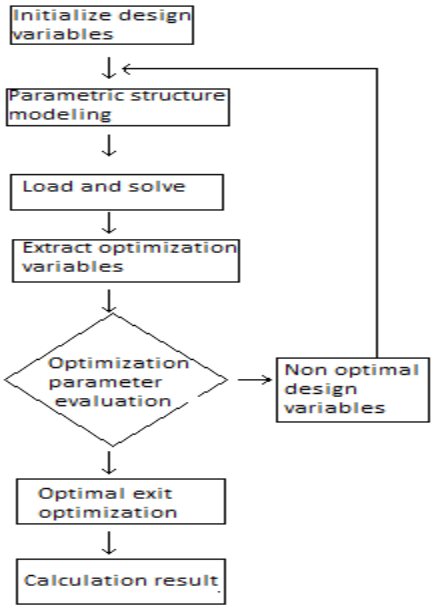


Figure 1. ANASYS structural optimization process

### 3.2.1 Optimization design of portal frame based on genetic algorithm

Genetic algorithm (GA) is a heuristic stochastic search algorithm based on the evolution of species. The genetic evolution of the "survival of the fittest, liezhe eliminated" thought into the algorithm, through the simulation of Mendel's theory of genetic variation maintained in an iteration (portal steel structure) excellent mode, while searching a better model; through the evolution of group and search problems (meet the strength and stiffness of stability constraint specification implementation using at least the steel) optimal solution. For an optimization problem, the GA optimization process is as follows:

(1) Select a certain number of parameters of the steel section of the portal structure to form the initial population, and make it $P(t)$. And evaluate the constraint degree of each variable.

(2) Whether the convergence criteria of the judgment algorithm satisfy the constraint criteria. If satisfied, execute (7); otherwise, perform the following steps.

(3) Randomly select parameter variables from the breeding pool for cross operation and mutation operation to produce offspring, and make $C(t)$.

(4) Evaluate the constraint degree of $C(t)$.

(5) According to the degree of constraint, select n individuals from $P(t)$ and $C(t)$ to make $P(t+1)$.

(6) make $t = t+1$, and return step (2).

(7) Output the optimal individual and population averages and so on.

The advantage of the genetic algorithms:

(1) Does not require prior knowledge of the problem, only one parameter evaluation function to give the solution of constraint variables. In the optimization process, no derivatives are needed, sensitivity analysis is not necessary, linear and nonlinear problems, mixed variables and continuous variables can be treated in the same way.

(2) The genetic algorithm is a group searching together in the solution space, each section and geometric variable of the portal frame, and the result is the global optimal solution under the whole force.

Disadvantages of genetic algorithms:

The design variables of genetic algorithm with binary string, for discrete optimization problems, but for continuous variables or mixed discrete and continuous optimization problem ability is insufficient; will produce premature convergence, random walk search, slow phenomenon.

### 3.3 Mathematical programming

Mathematical programming is the structural optimization problems into mathematical programming form to solve the problem, which is in the design space, the feasible region consists of equality constraints and inequality constraints Hypersurfaces in half space, the feasible point is located in the smallest objective equivalent plane, it is the optimal solution of the problem. The mathematical programming methods used in structural optimization are nonlinear programming, and sometimes linear programming. Linear programming solution is more mature, do not explain.

Nonlinear programming means that the objective function or the constraint equation is the nonlinear function of the design variable. Most of the structural design optimization is constrained nonlinear programming problems. There are several types of methods to solve this problem: it does not make the conversion but the demand analysis of the derivative methods, such as gradient projection method; no direct search method conversion does not need to lead, such as complex method; using linear programming to successive approximation, such as sequential linear programming method; for the unconstrained extremum problem solving such as, the penalty function method. The author takes penalty function [15] as an example to explain its optimization process.

#### 3.3.1 Optimization of penalty function for variable section portal frames

Penalty function transforms the constrained optimization problem into an unconstrained optimization problem. The optimum design of portal frames is a design problem under the conditions of multi variables (flange width, thickness, web height, number of nodes, etc.), multi constraints (geometric side constraints, physical constraints). The interior penalty function is used to transform the design into a mathematical programming method, which can better solve the optimal design problem of variable section portal frames. The optimization effect can reach 15% of the provincial target [16].

Its mathematical model can be expressed as follows:

Design variable quantity: $X=[x_0,x_1,x_2,x_3,\cdots,x_n]^T$

Objective function: $\min f(X)=f(x_0,x_1,x_2,\cdots,x_n) \quad X\in E^n$

Inequality constraint: $s.t.\ g_i(X)=g_i(x_0,x_1,x_2,\cdots,x_n)\geq 0 \ \ (i=1,2,3,\cdots,m)$

By introducing penalty factor (parameters) $\gamma$ , construct a new objective function, penalty function: $P(X)=f(X)+\gamma^{(k)}\sum_i^m \frac{1}{g_i(X)}$

The $\gamma(k)$ is the penalty iteration factor $\gamma(k)>0$ in item $k$ , and the sequence $\{\gamma^{(k)}\}$ is dropped from item to item; $\gamma^{(k)}\sum_i^m \frac{1}{g_i(X)}$ is the penalty item. When the penalty item $\left|\gamma^{(k)}\sum_i^m \frac{1}{g_i(X)}\right|\prec\varepsilon$ satisfies the constraint condition, the optimal solution is obtained; if not satisfied, the $k=k+1$ continues to iterate until the constraint condition is satisfied.

At present, the penalty function has the advantage of optimizing the portal frame of the penalty structure: converting the constrained nonlinear programming problem into the unconstrained extremum problem, reducing the computational complexity and improving the efficiency. The disadvantage is that the penalty function is not widely popularized in the optimization of portal frames, and the optimization range of portal frames is very narrow. The study on the portal frames with variable cross-section is limited and the scope of application is limited.

## 4. Conclusion

Although portal frames have a wide application prospect in China, there are various kinds of gabled frames, most of the portal frames are conservatively designed and cost much higher than that of reinforced concrete. The optimization of portal frames has become a major problem in its extensive application. Through the author's large number of portal frame optimization research and literature reading, summed up the following conclusions:

1. The optimal criterion, bionics method, mathematical programming method are respectively optimized theory into computer program based on the parametric analysis, the utility model has the advantages of simple operation, fast calculation speed and high accuracy; the disadvantage is the complexity of programming, and the frame of the actual stress deviation.

2. The optimal criterion method is widely used, and its function is more powerful, especially ANSYS optimization software has been the favorite of researchers.

3. More than portal rigid frame optimization methods are mostly for variable cross-section portal frame, the new type of portal frame (such as corrugated web, portal frame, castellated beam, portal frame, etc.) optimization remains to be studied.

## Acknowledgements

The item is supported by the Opening Project of Sichuan Province University Key Laboratory of Bridge Non-destruction Detecting and Engineering Computing, item number: (16ZB0246) (15SB0122).

Sichuan Provincial Key Laboratory Opening Fund project, project name: multiple investment and financing mode selection of road and bridge infrastructure projects in Western China

Number: (2015QYY01).

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