Optimization Design of Trapezoidal Shed Supporting Structure

Ming Liu[1, a], Wenkai Li[1, b] and Kuan Zhao[2, c]

[1]College of Sciences, Xi'an University of Science and Technology, Xi'an 710000, China

[2]School of Mechanical Engineering, Xi'an University of Science and Technology, Xi'an 710000, China

[a]liuming1075@163.com, [b]2436399692@163.com, [c]272499698@qq.com

Abstract. Aimed at the optimum design problems of trapezoidal shed supporting structure, the concrete paper applies program building relevant trapezoidal shed supporting structural model, the simulation programs are based on the first order optimization method. Section size as design variables, the maximum stress as state variables and unit minimum volume as the design objectives, the design parameters of trapezoidal shed supporting structure is optimized by simulation programs. This method can offer a theoretical basis for trapezoidal shed supporting design.

Keywords: optimum design, shed supporting, first order optimization.

1. Introduction

With the increasing of depth and intensity of the mine, deep mining brings a series of problem, such as maintenance difficulties, roof accidents increase, rock burst and so on, the original safety countermeasures already can't meet the requirement of the deep mining. Roadway needs maintenance and overhaul for many times, the difficulty of roadway support significantly increased, the security can't guarantee, support cost increase and the decrease of the mine benefit, such factors has become a key restricting for the mine construction. therefore, controlling surrounding rock deformation of roadway effectively and choosing the reasonable support[1]-[4] mode becomes the key technical problems of deep roadway maintenance, we must fully grasp the stress distribution of original rock and determine the stability of roadway surrounding rock conditions, so we can select of support forms and optimize the supporting parameters, etc.

2. The Determination of Supporting Loads

The calculation of roadway roof pressure can adopt traditional natural equilibrium arch theory, computation formula as follows

$$q_d = \frac{4}{3}\frac{\gamma a^2}{f} \tag{1}$$

The horizontal pressure force can be considered impacting on both sides of the supporting structure, the size of distributed load which impact from the top to the bottom of the underground engineering can be calculated according to the vertical pressure coefficient and lateral pressure coefficient, thus the size of the horizontal pressure of surrounding rock is

$$q_c = \lambda q_d \tag{2}$$

Where λ is the lateral pressure coefficient. When determine the outside load impacted on the supporting, we can undertake the design of roadway supporting according to the mechanical properties of supporting.

3. Optimization Design Method

The paper uses the first order optimization method which uses the first order partial derivative of state variables and objective function for the design variables, the constrained problem can be translated into the non-restraint problems by adding the penalty function for the objective function. Search can be conducted by using the derivative of the objective function and penalty function in the design space. In the iteration, the search direction determined by gradient calculation (the most rapid descent method and conjugate gradient method), by using linear search method to minimize the non-restraint problems. Therefore, each iteration has a series of iterations (including search direction and gradient calculation).

The constrained problem can be translated into the non-restraint problems by adding the penalty function for the objective function, the form of objective function after the transformation is as follows

$$Q(X,q)=\frac{f}{f_0}+q[\sum_{i=1}^{N}P_X(X_i)+\sum_{j=1}^{H}P_u(u_j-\bar{u}_j)+\sum_{M=1}^{M}P_\sigma(\sigma_m)] \quad (3)$$

Where Q objective function of the unconstrained, dimensionless; P_s is constraint penalty function of the design variable S ; P_u is penalty function of state constraint function $u_j-\bar{u}_j$; P_σ is penalty function of state constraint function σ ; Q is punish factor; f_0 is the reference objective function value from the current design sequence .

For design variables and state variables with upper and lower bounds, and their penalty function as the following form

$$P_s(s_i)=\left[\frac{s_i}{-a_i}\right]^{2\lambda}+\left[\frac{s_i}{LN_p/k+a_i}\right]^{2\lambda} \quad (4)$$

Where a_i is allowable error for constraint

$$\lambda=\begin{cases}10e+6 & s_i<0 or s_i>LN_p/k \\ 10e-6 & 0\le s_i\le LN_p/k\end{cases}$$

$$P_u(u_j-\bar{u}_j)=P_u\left(\frac{u_j-\bar{u}_j}{\underline{u}-\beta_j}\right)^{2\lambda}+\left(\frac{u_j-\bar{u}_j}{\bar{u}-\beta_j}\right)^{2\lambda} \quad (5)$$

Where β_j is allowable error for constraint

$$\lambda=\begin{cases}10e+6 & u_j-\bar{u}_j<u or u_j-\bar{u}_j>\bar{u} \\ 10e-6 & \underline{u}\le u_j-\bar{u}_j\le\bar{u}\end{cases}$$

$$P_\sigma(\sigma_m)=\left(\frac{\sigma_m}{-[\sigma]-\gamma_m}\right)^{2\lambda}+\left(\frac{\sigma_m}{[\sigma]+\gamma_m}\right)^{2\lambda} \quad (6)$$

Where γ_m is allowable error for constraint.

$$\lambda=\begin{cases}10e+6 & \sigma_m<-[\sigma] or \sigma_m>[\sigma] \\ 10e-6 & -[\sigma]\le\sigma_m\le[\sigma]\end{cases}$$

4. Example

Take some mine roadway as an example. the size of the top is 4 , the size of the bottom is 4, the volume-weight of overburden $\gamma=1380$ kg/m^3, the lateral pressure coefficient of rock (the ratio of horizontal stress and vertical stress) is 0.5, Cohesive force of rock $c=0.2$MPa, angle of internal friction $\varphi=35^\circ$,firmness coefficient $f=1.5$. roof pressure $q_d=48085$N/m , lateral pressure $q_2=41.9k$N/m $q_c=24043$N/m , supporting structure is trapezoidal shed supporting structure, choose to use $9^\#$ I-shaped steel, the material yield limit is 375 MPa, the mean of elasticity modulus $E = 205GPa$, μ=0.3 , section size as design variables, $0.07\text{m} \le B \le 0.08\text{m}$, $0.08\text{m} \le H \le 0.1\text{m}$, $0.01\text{m} \le D \le 0.015\text{m}$, $0.007\text{m} \le T \le 0.009\text{m}$.

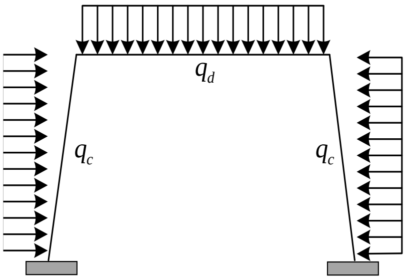

Fig. 1 Applied load.

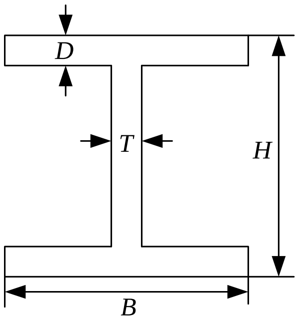

Fig. 2 The section size

In this paper, optimization method were executed by using first order optimization method, the maximum stress curve along with the change of the number of iterations as shown in Fig.(3), Fig.(4)-Fig.(7) is the optimization results of section size, the total volume curve along with the change of the number of iterations as shown in Fig.(8).

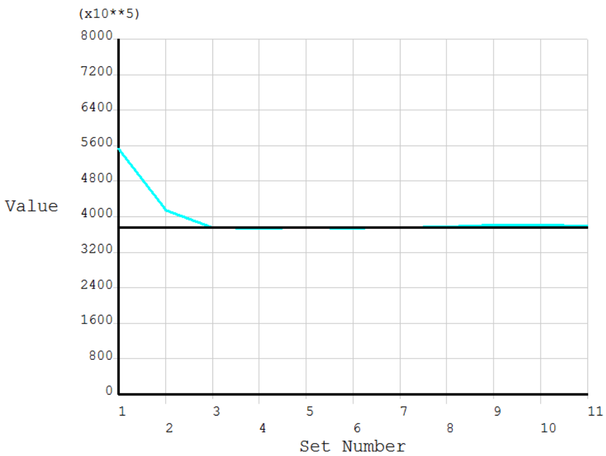

Fig. 3 The maximum stress curve

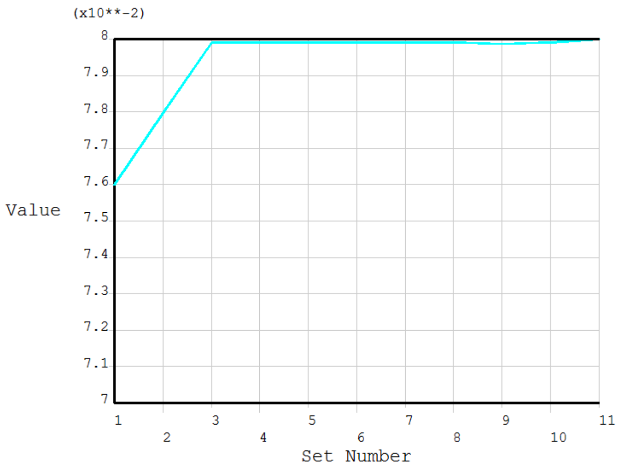

Fig. 4 The cross section width B curve

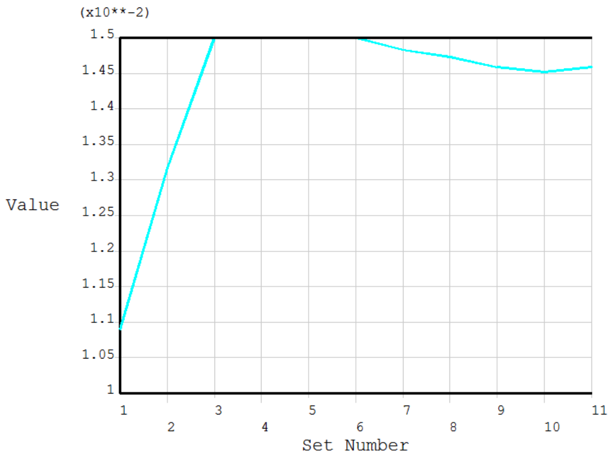

Fig. 5 Flange thickness D curve

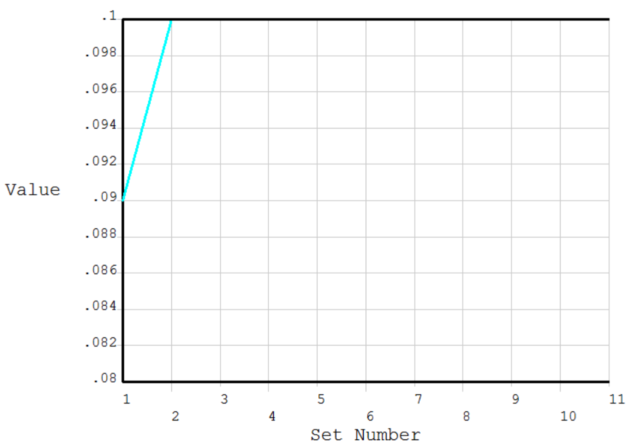

Fig. 6 Cross section height H curve

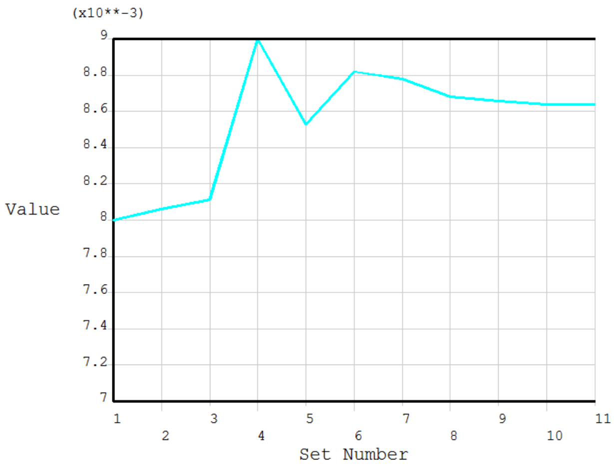

Fig. 7 The web thickness T curve

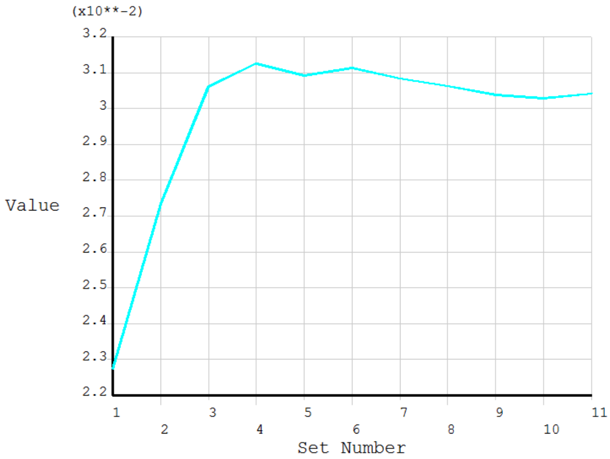

Fig. 8 The total volume curve

5. Conclusion

The paper based on the trapezoidal shed supporting structure of soft rock roadway, established the finite element model of trapezoidal shed supporting structure, the design parameters of trapezoidal shed supporting structure is optimized by first order optimization method, the best of the section sizes of trapezoidal shed supporting structure were got by the computer program.

Acknowledgements

China Postdoctoral Science Foundation (2014M562519XB).

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