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OPTIMUM DESIGN OF ARCHED ROADWAY SUPPORT STRUCTURE

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ABSTRACT

Aimed at the optimum design problems of arch retaining structure, the concrete paper applies program building relevant arch retaining structural model, the simulation programs are based on the zero 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 arched retaining structure is optimized by simulation programs. This method can offer a theoretical basis for roadway supporting structure design.

KEYWORDS

Optimum design, support, arch, roadway.

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 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 [1-6].

2. THE DETERMINATION OF SUPPORTING LOADS.

Effect on the arch outside loads, the main load is the pressure of surrounding rock; it is usually a main load impacting on the underground structure. Based on a study, the surrounding rock pressure impacted on the arch of supporting is divided into vertical pressure force and horizontal pressure force of surrounding rock [7]. For the cavity of the average level, the vertical pressure force of surrounding rock is the main force which is also the main research content of the surrounding rock pressure .In hard formation, the horizontal pressure force of surrounding rock is very small, frequently it can be neglected; In soft stratum, the horizontal pressure force of surrounding rock is larger, it must be considered in calculation.

When we determine the surrounding rock pressure, due to the influence factors of surrounding rock pressure is more and more complex, there is not completely unified calculation method so far. Platts theory is widely used in the design of underground engineering in China. To this end, this paper uses the Platts theory to determine the surrounding rock pressure. Platts theory has two basicassumptions.

a) In view of the stratum are cut by many joints and cracks which are weakstructural plane, so that the surrounding rock can be treated as the loose body in a certain extent. For hard rock, Platts suggest people to compensate the ignored and actual existence of cohesive force by increasing friction coefficient between particles, the friction coefficient increased is referred to as Protodyakonov coefficient;

b) Thinking rock after excavation, due to the surrounding rock stress redistribution, the pressure arch is formed above the cavern, the weight of the rock in the arch is the surrounding rock stress impacted on the lining or the supporting.

2.1 The Determination of the Pressure Arch Height

According to Platts theory, the pressure arch height is

$$h_1 = \frac{a_1}{f} \tag{1}$$

$$a_1 = a + h\tan(45^\circ - \frac{\varphi}{2}) \tag{2}$$

Where a is half across of cavity; h is the cavity height; a_1 is half across of the pressure arch; φ is internal friction angle of rock; f is Protodyakonov coefficient.

2.2 The Determination of the Size of the Vertical Pressure Force

The theory is that: the above of it will form a natural arch after excavation in loose medium of a certain cohesive force, and vertical pressure impacted on the supporting structure is the weight of loose rock mass within the scope of damage (natural arch), thus, the size of the vertical pressure of surrounding rock is

$$q_1 = \gamma h_1 \tag{3}$$

Where γ is the volume weight of surrounding rock

2.3 The Determination of the Size of the Horizontal Pressure Force

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

$$q_2 = \lambda q_1 \tag{4}$$

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. can be used by the method similar to oblique beam, the load can be treated as distribution along the axis of curved beam, and then the loads are decomposed into two parts that are the radial and tangential. Study showed curve is more complex than linear decomposition, structure diagram as shown in Figure 1. it can be exploded as follows [8],

2.4 Applied Load

Due to the loads impacted on the roadway arch supporting structure are not the radial and tangential distributed load, with regard to such distributed load

$$q_{SV} = \frac{q_1}{\left(1+y'^2\right)},\quad q_{SP} = \frac{q_1 y'}{\left(1+y'^2\right)} \tag{5}$$

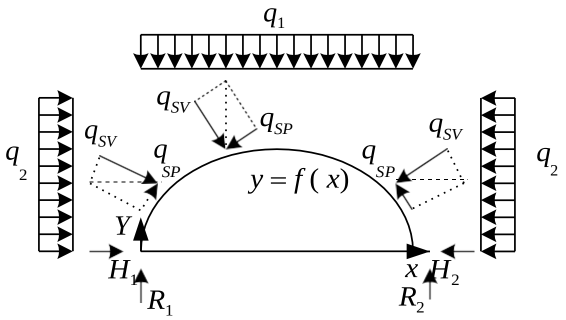

Figure 1: Applied load.

Where y' is $\mathrm{d}f(x)/\mathrm{d}x$.

When elements are divided small enough, $y' \approx \Delta y/\Delta x$ can be used, Δx and Δy are the coordinate difference of two nodes in element. When the size of elements is appropriate, the results with sufficient accuracy can be calculated.

3. OPTIMIZATION DESIGN METHOD

The paper uses the zero order optimization method which is also called the direct method, it is the universal approximation of function optimization method [9,10]. Using the least squares approximation to calculate a function surface to fit the solution space, and then seeking extreme value on the function surface. Making all constraint conditions close to its upper and lower limits in Iterative process, So that we can effectively deal with the majority of the engineering problems.

Optimization problem with constraints

$$\begin{aligned} &find\ X = [x_1, x_2, \cdots x_n] \\ &\min f(\mathrm{X}) \end{aligned} \tag{6}$$

$$s.t.\quad \begin{aligned} &\underline{x_i} \le x_i \le \overline{x_i}\left(i = 1, 2, 3\cdots m_1\right) \\ &g_i(x) \le \overline{g_i}\left(i = 1, 2, 3\cdots m_2\right) \\ &\underline{h_i} \le h_i(x)\ \left(i = 1, 2, 3\ \cdots m_3\right) \\ &\underline{w_i} \le w_i(x) \le w_i\quad \left(i = 1, 2, 3\cdots m_3\right) \end{aligned} \tag{7}$$

For the objective function, assume that the fitting formula for square fitting, the fitting formula is

$$T = a_0 + \sum_{i}^{n} a_i x_i + \sum_{i}^{n}\sum_{j}^{n} b_{ij} x_i x_j \tag{8}$$

For curved surface fitting, first of all, by way of definition or randomly generated K set of design variables, the corresponding calculation results of each objective function and state variables were worked out through the finite element method. The total error of weighted least squares error can be concluded by each group the results

$$\begin{aligned} E^2 &= \sum_{j=1}^{K}\Phi^{(j)}\left(t^{(j)} - T^{(j)}\right)^2 \\ &= S\left(a_0, a_1, \cdots b_{n,n}\right) \end{aligned} \tag{9}$$

Where K is the number of groups of current design variable ; $t^{(j)}$ is the corresponding T value of j set of design variables which was calculated by the finite element method; $T^{(j)}$ is the T value of j set of design variables which was calculated by the approximate algorithm; $\Phi^{(j)}$ is the weight of j set of design variables, its value can be determined by j set of design variables with the corresponding design variables space distance, and the objective function value.

According to the principle of least squares, the minimum of E^2 can be got, the regular equations is

$$\frac{\partial S}{\partial a_i} = 0,\quad \frac{\partial S}{\partial b_{ij}} = 0 \tag{10}$$

Where a_i and b_{ij} can be obtained by solving this equation, the objective function and state variables can also be obtained.

For the constraints of the design variables and state variables, it can be transformed into unconstrained equation by adopting the method of penalty function, thus a constrained optimization problem was transformed into the solution of unconstrained minimum value.

$$\hat{f} = \hat{f}(X) \tag{11}$$

$$\hat{g}_i(x) \le \overline{g}_i + \partial_i \tag{12}$$

$$\underline{h}_i \le \hat{h}_i(x) + \beta_i \tag{13}$$

$$\underline{w}_i - \overline{\omega}_i \le \overline{w}_i(x) \le \overline{w}_i + \overline{\omega}_i \tag{14}$$

$$\begin{aligned} F\left(X, p_k\right) &= \hat{f} + f_0 p_k \Big(\sum_{i=1}^{n} X\left(x_i\right) \\ &+ \sum_{i=1}^{m_1} G\left(\hat{g}_i\right) + \sum_{i=1}^{m_2} H\left(\hat{h}_i\right) + \sum_{i=1}^{m_3} W\left(\overline{w}_i\right)\Big) \end{aligned} \tag{15}$$

Where x_i is the design variables; G , H , W are the penalty function of state variable; p_k is the response surface parameters; f_0 is introduced for the unit conformity ; ∂_i , β_i , ω on behalf of their tolerance. When design variables (or state) close to the limit, the penalty function $X\left(x_i\right)$ value increased dramatically.

$$X\left(x_i\right) = \begin{cases} c_1 + c_2 / \left(\overline{x} - x_i\right) & x_i < \overline{x} - \varepsilon\left(\overline{x} - \underline{x}\right) \\ c_3 + c_4 / \left(x_i - \overline{x}\right) & x_i \ge \overline{x} - \varepsilon\left(\overline{x} - \underline{x}\right) \end{cases}$$

Where are coefficients; ε is a smallest positive.

4. RESULTS AND CONCLUSIONS

Take some mine roadway as an example. The width of roadway construction is 4 m, the height of it is 2 m. the buried depth of it is about 443 m, the volume-weight of overburden γ = 24 kN/m^3, the lateral pressure coefficient of rock (the ratio of horizontal stress and vertical stress) is 0.5, Cohesive force of rock, angle of internal friction $\varphi = 35$, rotodyakonov coefficient f = 1.2 roof pressure q_1 = 83.7 kN/m, lateral pressure q_1 = 41.9 kN/m, , supporting structure is the arch support, choose to use 9# I- shaped steel, the material yield limit is 375 MPa, the mean of elasticity modulus $E = 205$ GPa, μ=0.3 , section size as design variables, 0.07 m $\le B \le$ 0.08 m, 0.08 m $\le H \le$ 0.1 m, 0.01 m $\le D \le$ 0.015 m, 0.07 m $\le H \le$ 0.09 m.

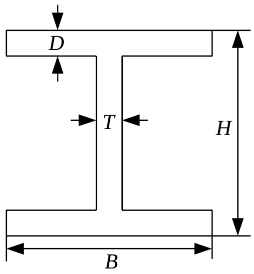

Figure 2: The section size.

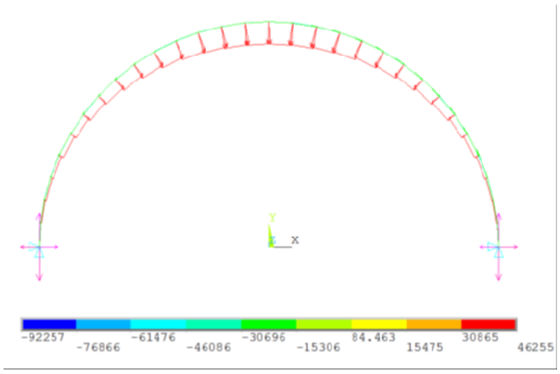

Figure 3: The stress nephogram of supporting structure.

Table 1: The results of numerical simulation.

	SET 1	SET 2	SET 3
stress	0.31264E+09	0.29020E+09	0.26115E+09
B	0.76000E-01	0.78472E-01	0.75376E-01
H	0.90000E-01	0.89144E-01	0.92358E-01
D	0.10900E-01	0.11940E-01	0.14239E-01
T	0.80000E-02	0.83847E-02	0.70067E-02
Volume	0.13832E-01	0.15205E-01	0.16292E-01
	SET 4	SET 5	SET 6
stress	0.29123E+09	0.34243E+09	0.24493E+09
B	0.74691E-01	0.76951E-01	0.75297E-01
H	0.86406E-01	0.81400E-01	0.99790E-01
D	0.13964E-01	0.11736E-01	0.13158E-01
T	0.81643E-02	0.72249E-02	0.73018E-02
Volume	0.16099E-01	0.13972E-01	0.15814E-01
	SET 7	SET8	SET 9
stress	0.36606E+09	0.37827E+09	0.37559E+09
B	0.71678E-01	0.70490E-01	0.70577E-01
H	0.83603E-01	0.84770E-01	0.85820E-01
D	0.10900E-01	0.10256E-01	0.10069E-01
T	0.79994E-02	0.79546E-02	0.79437E-02
Volume	0.12918E-01	0.12291E-01	0.12203E-01

In this paper, optimization method were executed by using zero order optimization method, the stress nephogram of supporting structure was obtained as shown in Figure 3, The numerical simulation results are shown in Table 1, the maximum stress curve along with the change of the number of iterations as shown in Figures 4 and 5. Figure 8 is the optimization results of section size, the total volume curve along with the change of the number of iterations as shown in Figure 9.

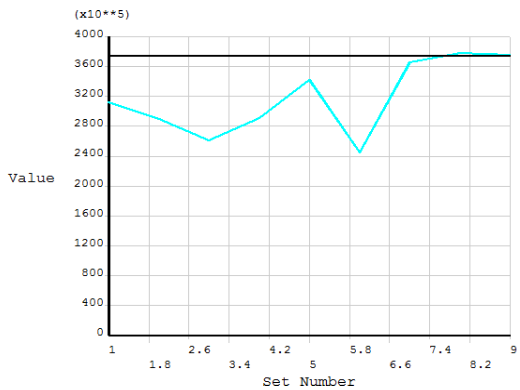

Figure 4: The maximum stress curve along with the iterations.

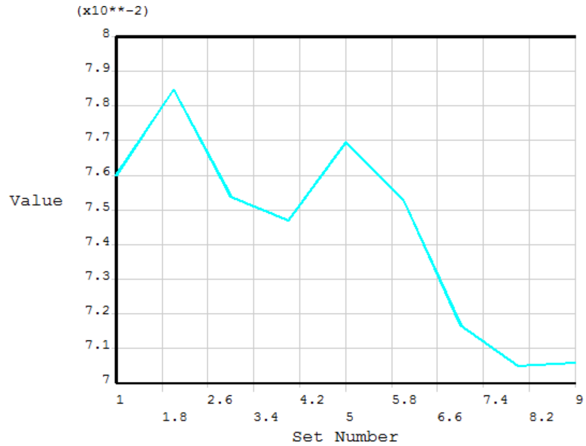

Figure 5: The cross section width B curve along with the iterations.

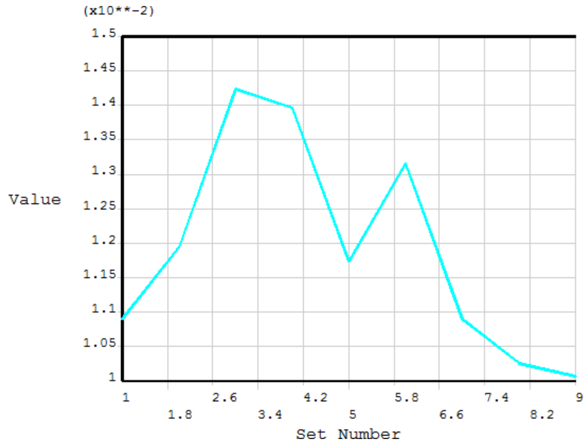

Figure 6: Flange thickness D curve along with iterations.

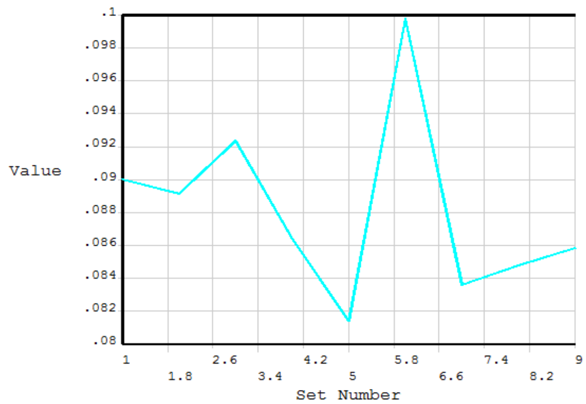

Figure 7: Cross section height H curve along with iterations.

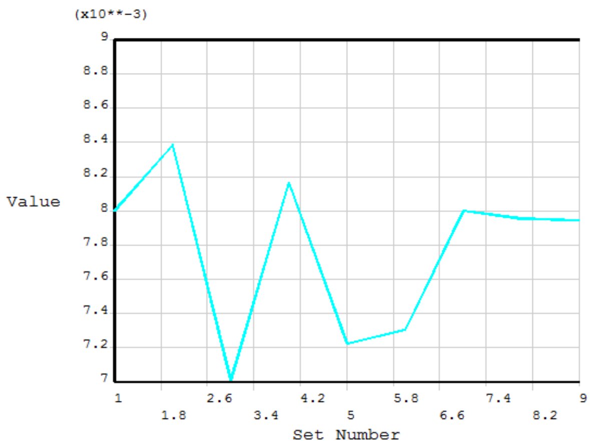

Figure 8: The web thickness T curve along with iterations.

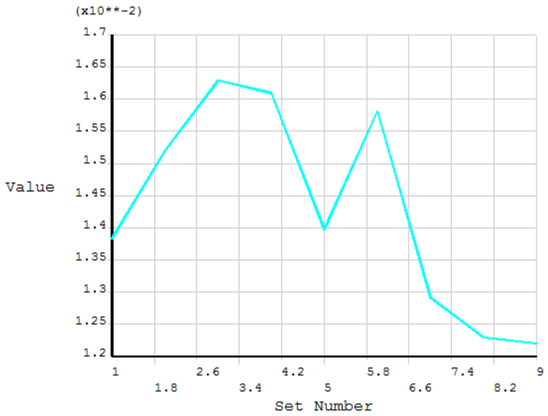

Figure 9: The total volume curve along with iterations.

The paper based on the arched retaining structure of soft rock roadway, established the finite element model of arched roadway support structures, the design parameters of arched retaining structure is optimized by simulation programs, the best of the section sizes of arched retaining structure were got by the computer program.

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