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Study on Mechanical Characteristics of Tunnel Support System in Sandy Cobble Stratum

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Abstract: Because the sand gravel stratum with loose structure, good gradation, easy disturbance, poor stability, deformation and other characteristics of long duration, large deformation and collapse failure phenomenon is extremely easy to cause in the tunnel construction, leading to a primary support structure for strong deformation or even destruction, serious impact on the tunnel construction and safety, is one of the main problems encountered in tunnel construction. The paper based on the engineering background of Gongboxia sand gravel stratum tunnel, studied the Sandy pebble tunnel primary support stiffness and the influence of strength characteristics, also mechanical impact characteristics of secondary lining and timing. By studying the mechanical behavior of tunnel support system, the paper puts forward the parameters of the initial support of the sand gravel tunnel, and makes clear the relationship between the stress of the supporting arch and the stress of the lining and the timing of the two lining. The research results can provide supporting design reference for sand pebble stratum tunnel and similar projects.

Keywords: Tunnel, Sandy Cobble Stratum, Support, Mechanical Property

1. Introduction

With the improvement of the traffic network in our country, the implementation of the western development strategy, the highway construction and development of western region quickly, springing up under complicated geological conditions of highway tunnel. Tunnel in construction process, due to the design, construction and complicated geological conditions, made in the construction process of tunnel supporting structure Phenomenon such as deformation, destruction, even causing the initial supporting structure contamination limit, such as large deformation of surrounding rock and soil slip, serious impact on the tunnel construction safety and cause great economic losses. Qinghai area tunnel crossing is common adverse geological conditions such as gravel layer, and the characteristics of gravel or high compactness, big size boulders content, grain size distribution, permeability is strong, and pebble intensity is higher, the difficulties caused by tunnel excavation and supporting, and thus the emphasis and difficulty in sandy pebble stratum tunnel construction is concentrated in the hole to the design of the supporting system construction [1-2]. Therefore, for highway tunnels under complex geological conditions, accurate to obtain the mechanical behavior of supporting structure in the construction process and provide scientific basis for dynamic design, has become a problem must be solved in the process of construction [3-4].

2. Project Summary

Gongboxia tunnel located in XunHua County of qinghai province in China, overlooking the Yellow River on the right bank of river in reservoir area, import on the east side dam is about 1.5km slope toe, exports in the dam area in lower branch lander on the right bank slope of about 1km, tunnel import 584m across the diluvial sand gravel stratum. Because of special regional tunnel location distribution of large cross section of sand pebble stratum, may cause in the process of the excavation of stratum deformation, appear easily local even wider collapse, endanger the tunnel construction safety, combined with the density of silty mudstone grout diffusion in advance, and has become a sandy pebble stratum tunnel into the hole of the main causes of difficulty. Therefore, in the hole during the tunnel construction of supporting system of the design and construction is the key to ensure the safety of the tunnel.

Figure 1. *Tunnel hole to support.*

Figure 2. *Steps collapse in tunnel excavation.*

3. Analysis Method and Parameters

Value given the parameter sensitivity analysis and optimization, assuming that other parameters and indicators remain the same, only change the quantities to be analysed, study the change of surrounding rock and the change of structure mechanics response, from the trend of change and change sensitive characteristics of physical quantity value analysis, and further to determine the reasonable value range. Using FLAC^{3D} three-dimensional finite difference numerical analysis program [5-7]. Extract the calculated data that excavationed to the Middle of calculation model in the main process of calculation, namely stress and deformation results of the surrounding rock in 15m of the tunnel longitudinal.

3.1. Calculation Model

Value optimization calculation model by using the simplified model, the tunnel longitudinal take 30m, the tunnel surface ideal into a horizontal surface, tunnel buried depth uniformity. Computation simulation range: horizontal direction (x), tunnel wall to the left and right borders three times from each hole diameter, a total of 84m; Vertical direction (the z axis), up to the surface, the inverted arch is 3 times the distance to the bottom boundary hole diameter, about 40m; Tunnel longitudinal (y), 30m. Model as shown in the figure below.

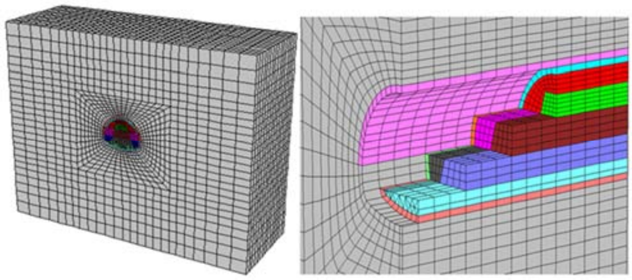

Figure 3. *Simplified model.*

Construction whole process of value simulation by using the accurate model, the tunnel longitudinal double hole according to the actual average length value of about 110m, the tunnel surface according to the terrain modeling. Simulating scope: horizontal direction (x), left and right tunnel hole to the left and right boundary net from the three times from each hole diameter, total length of about 160m; Vertical direction (the z axis), up to the surface, the inverted arch is 3 times the distance to the bottom boundary hole diameter, about 40m; Tunnel longitudinal (y), 120m. Model as shown in the figure below.

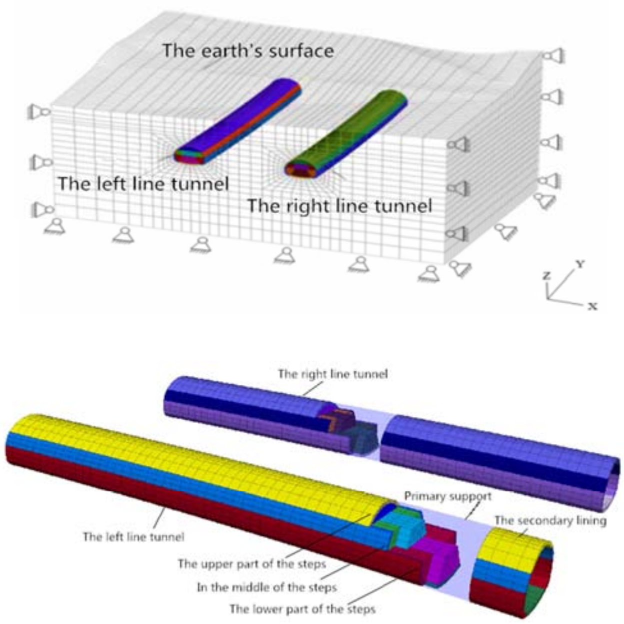

Figure 4. *3d simulation model.*

3.2. Material, the Unit and the Constitutive Relations

Surrounding the Mohr - Coulomb (Moore - Coulomb) elastic-plastic model, it can reflect geotechnical material yield stress and deviatoric stress with ball is closely related to the important features and is widely used in the study of geotechnical engineering. Mohr - Coulomb failure criteria of materials model is the tensile shear combination rule. Give three principal stress number, assume that $\sigma_1 \le \sigma_2 \le \sigma_3$, by Mohr - Coulomb failure criteria to determine the point A to point B failure envelope line f s = 0, namely rule of shear failure:

$$f^s = \sigma_1 - \sigma_3 + 2c\sqrt{N_\varphi} = 0 \tag{1}$$

Undermine envelope line from point B to point C that $f_t = 0$, said the tensile failure criteria, namely:

$$f_t = \sigma^t - \sigma_3 = 0 \tag{2}$$

Among them: φ - the friction Angle, c - cohesive force, σ_t -the tensile strength,

$$N\varphi = \frac{1+\sin\varphi}{1-\sin\varphi}$$

The Mohr - Coulomb material model, the tension strength of σ_t cannot exceed σ_3, maximum tensile strength $\sigma^t_{\max t} = \dfrac{c}{\tan\varphi}$.

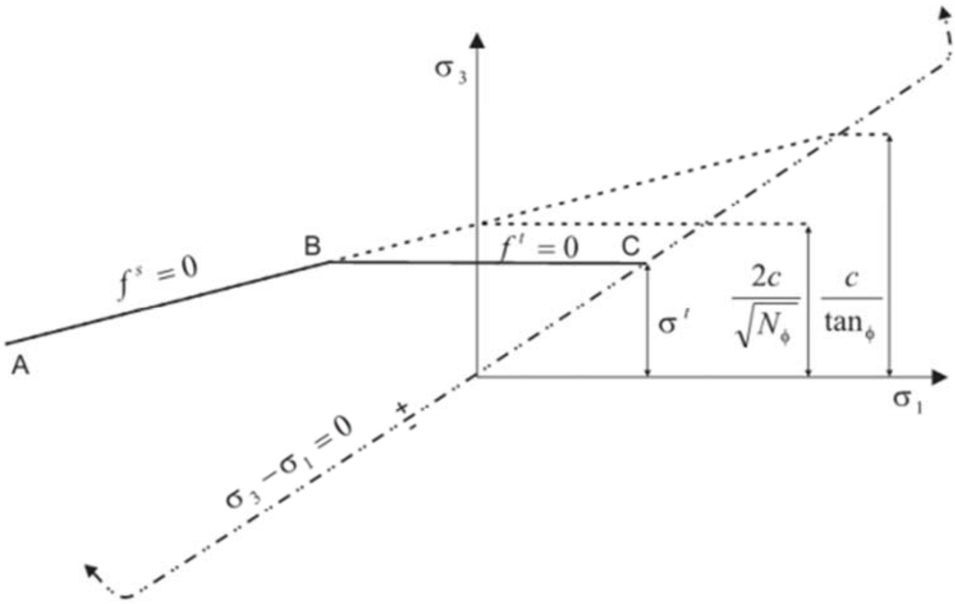

Figure 5. *Mohr - Coulomb strength criterion.*

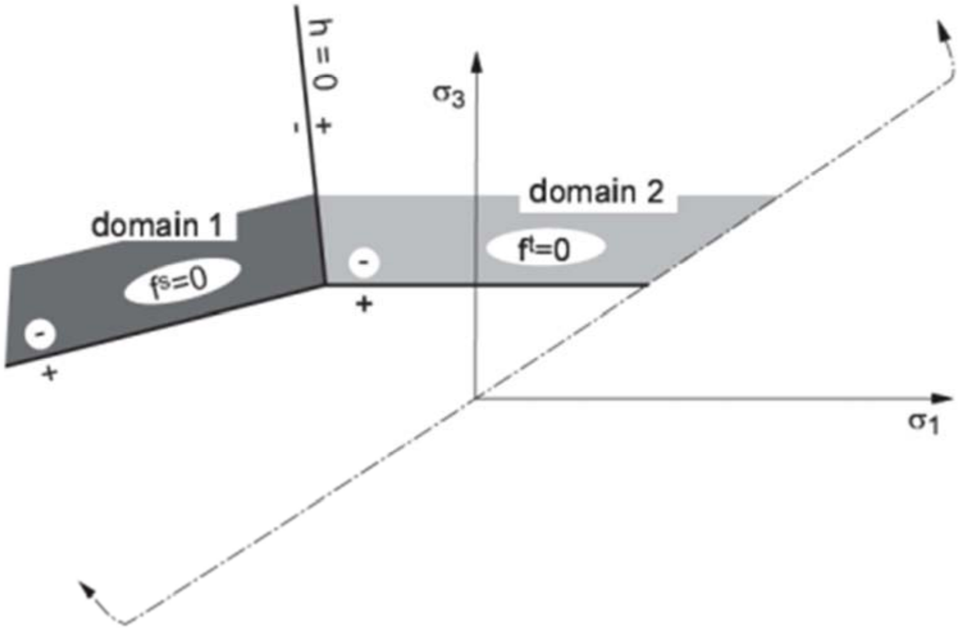

Figure 6. *Mohr - Coulomb flow rule.*

In Mohr - Coulomb elastic-plastic model, respectively with two gs and gt to define the potential function model of shear plastic flow and the tensile plastic flow rule.

Potential function g^s conforms to the associated flow rule, form is as follows:

$$g^s = \sigma_1 - \sigma_3 N_\psi \tag{3}$$

Among them: ψ for the expansion Angle, $N_\psi = \dfrac{1+\sin\psi}{1-\sin\psi}$

Potential function gt conform to the associated flow rule, in the form of: $g^t = \sigma_3$

$h(\sigma_1, \sigma_3) = 0$, The only definition of function is used to a given flow rule.

Among them, the function can be expressed as h type:

$$h = \sigma_3 - \sigma^t + \alpha^P(\sigma_1 - \sigma^P) \tag{4}$$

Type, α^p and σ^p given respectively by the following two type:

$$\alpha^P = \sqrt{1+N_\varphi^2} + N_\varphi \tag{5}$$

$$\sigma^P = \sigma^t N_\varphi - 2c\sqrt{N_\varphi} \tag{6}$$

Sprayed concrete using Shell (Shell) unit simulation, secondary lining of the Elastic (Elastic) model, the above two materials are subject to Elastic constitutive relation.

3.3. The Calculation Parameters

Hole to close short pipe roof support according to the equivalent simulation to improve the soil stiffness and strength. Sandy pebble physical and mechanical parameters determined by experiments; The parameters of the underlying sandstone and the reinforcement ring by adopting the combination of field experiment and literature data method to determine. Shotcrete and modulus of concrete parameters are in accordance with the relevant specification values.

Table 1. *Calculation parameter table.*

materials	severe/kN/m^3	Poisson's ratio	Modulus of elasticity /GPa	Cohesive force /MPa	Angle of internal friction /°	Reinforcing ring thickness /m
Sandy pebble	17.2	0.4	0.021	0	27	/
The weathered tuff	19.1	0.35	1	0.1	27	/
A great reinforcement ring	19	0.3	4.0	0.580	35	0.6
Primary support	23	0.25	23	/	/	0.3
The secondary lining	25	0.20	31	/	/	0.6

4. Early Supporting Stiffness Analysis

Sandy pebble formation, primary support must be applied immediately after excavation, forming the collapse of retaining structure to prevent leakage of sand, so the pressure of surrounding rock is not fully released, the primary support to external surrounding rock under high load. This section respectively set up buried deeply 10m, 15m, 20m, 25m, 35m and 50m 6 groups of calculation conditions, comparative analysis the early support force and deformation.

Simulation calculation of value rationality are simplified processing, according to the steps method of rotary work process constraints position for 20m division supremacy of excavation steps, take 2m excavation, gathering the deformation and stress factors were analyzed[8-9]. Simplified model and the actual mechanics results have certain differences, but not influence regularity and sensitivity analysis, can satisfy the requirements of the scope optimization.

4.1. Primary Support Internal Force

Sandy pebble tunnel primary support bending moment distribution is different from conventional formation tunnel, springing line structure above is under bending moment, and the value is generally greater than springing line the following parts. Jet grouting pile forepole besides blocks sand leakage, are taking a large number of load of surrounding rock, because forepole applied before the excavation, in situ stress arch department will basically all ACTS on the jet grouting pile, and after the primary support, jet grouting pile and its interaction of surrounding rock under pressure, stress release is short, the process of structure stress in a number of large, primary support results of the internal force is larger.

With the increase of buried depth, the initial supporting arch, arch shoulder, back, back to the arch foot arch center moment magnitude increases obviously, spandrel growth aggravate, the rest parts gradually slowing growth. Wall bending moment decreases with increasing buried depth, and presents the negative bending moment by moment towards developing trend. More than 25m depth, the inverted arch arch foot are bending over 200kN·m, quantity is larger, primary support to satisfy the demand of the bearing stiffness and strength to demand higher. Buried depth of more than 50m, the bending moment of 305kN·m. spandrel is greater than the inverted arch arch foot are bending moment, and the trend of increase with the increase of buried depth bending moment is amplified, sandy pebble large depth of the tunnel, the arch shoulder as strength of primary support damage control parts.

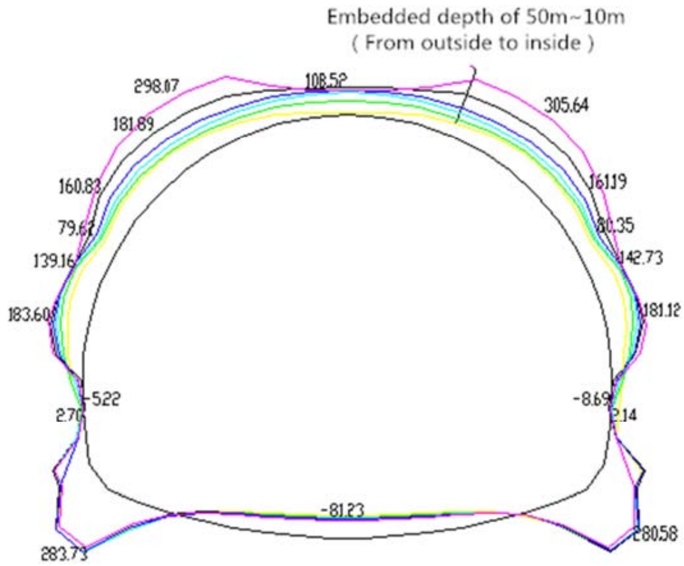

Figure 7. *Early supporting bending moment.*

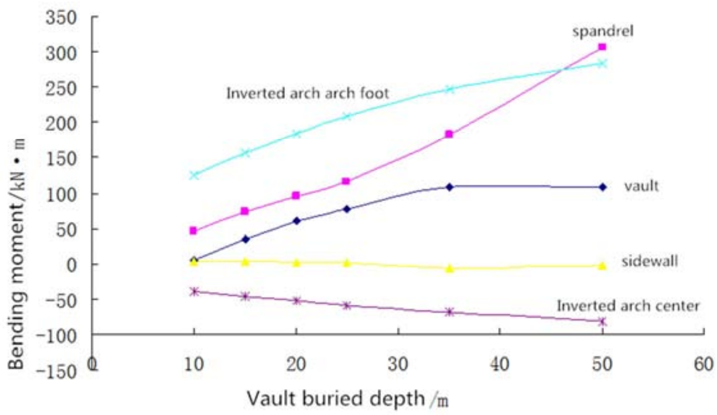

Figure 8. *Primary support relation between bending moment with buried depth.*

Basically the same axial force and bending moment distribution in "on the big small" form, Pipe roof is passed to the early support of surrounding rock pressure, springing line above the structure internal force value is very big, when buried deeply 50m arch of axial force of 3000 kn. Arch, arch shoulder axial force increase significantly with the increase of buried depth; Wall and the back for the arch foot axial force increased with the increase of buried depth and the same, but growth is smaller, the curve is flat; Inverted arch center axial force basic consistent.

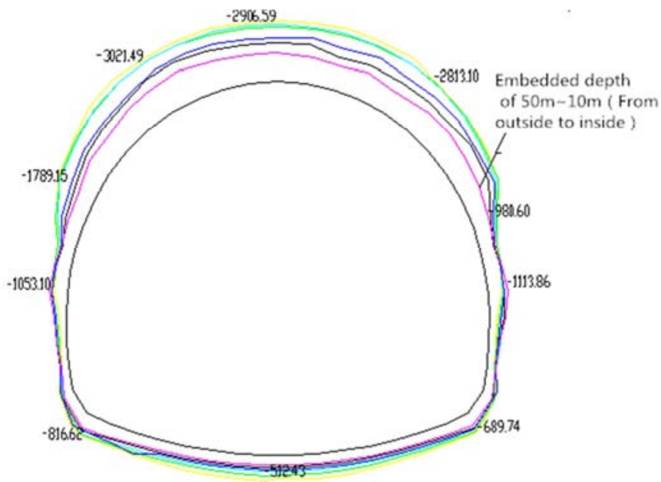

Figure 9. *Early supporting axial force.*

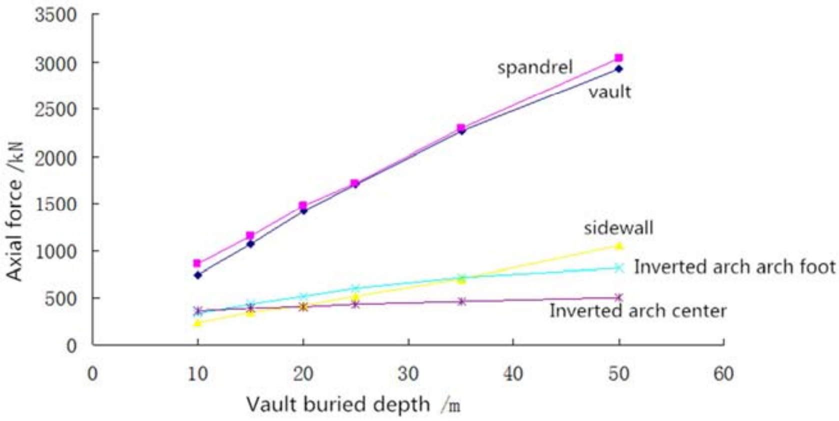

Figure 10. *Early supporting axial force changing with depth.*

4.2. Deformation of Primary Support

Settlement increases basic linearly with the increase of buried depth, when 50m arch sedimentation depth of 26.8cm; Convergence is also increased with the increase of buried depth, growth slowed.

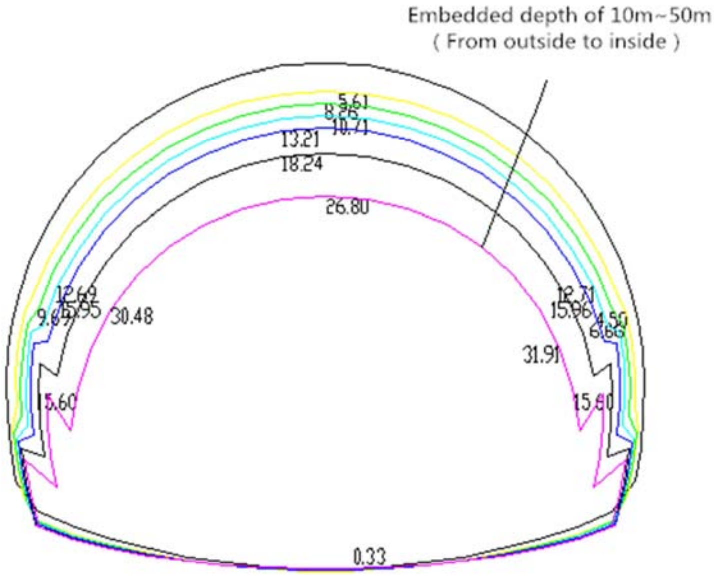

Figure 11. *Deformation of primary support.*

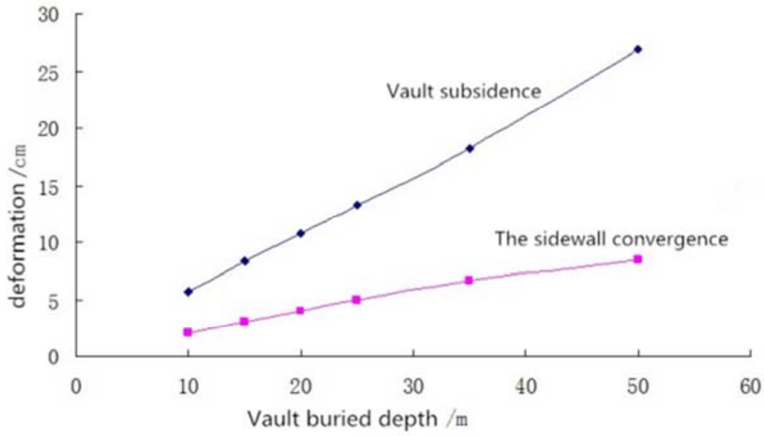

Figure 12. *Deformation of primary support changing with depth.*

4.3. Sandy Pebble Tunnel Primary Support Scope

Based on results of calculating the internal force are calculated respectively different embedded depth of the initial supporting safety coefficient. Reference to "detailed rules for the design of highway tunnel" (JTG D70-2010 / T) recommend checking method of internal force, supporting steel arch and shotcrete initial internal force sharing principle is: the axial force of steel arch and shotcrete to share, and bending moment is only borne by steel arch. Sprayed concrete safety coefficient is 2.0, the steel arch safety coefficient of 1.7.

Calculation of the cross section axial force and bending moment of N, M, respectively is:

Sprayed concrete bear axial force:

$$N_h = N\frac{A_h E_h}{A_h E_h + A_g E_g} \tag{7}$$

Accept the bending moment of sprayed concrete,

$$M_{\mathrm{g}} = 0 \tag{8}$$

Accept the axial force of steel arch shelf,

$$N_g = N\frac{A_g E_g}{A_g E_g + A_h E_h} \tag{9}$$

Steel arch shelf bear bending moment:

$$M_Z = M \tag{10}$$

Sprayed concrete section stress shall meet the following requirements:

$$K_{hy} N_h \le \alpha R_{hy} A_h \tag{11}$$

Steel arch shelf compressive stress shall meet the following requirements:

$$K(\frac{N_g}{A_g} + \frac{M_g}{W_g}) \le R_{gv} \tag{12}$$

Steel arch tensile stress should meet the following requirements:

$$K_g(\frac{N_g}{A_g} - \frac{M_g}{W_g}) \le R_{gl} \tag{13}$$

Type:

N, M - per unit length in the check section axial force and bending moment (kN, kN - m);

E_h, E_g - sprayed concrete and the elastic modulus of steel arch (kPa);

N_h, N_g - the sprayed concrete and steel arch bear axial force (kN);

K_{hy} - sprayed concrete compressive ultimate strength safety factor;

K_y - the compressive ultimate strength of steel arch safety factor;

A_h, A_g - sprayed concrete and steel arch calculated cross section area;

W_g -Steel arch bending stiffness (m^3);

α - eccentric effect coefficient, according to table access;

h - calculating the thickness of the cross section (m).

By the above formula calculation it is concluded that: (1) sand pebble tunnel buried depth is less than 35m, early bolting arch model should not be less than I22b, thickness of sprayed concrete desirable 28cm, arch span should not be more than 0.5m, can meet the demand of the support strength; (2) the buried depth is more than 35m, less than 50m, early bolting arch model should not be less than I25b, thickness of sprayed concrete desirable 32cm, arch span should not be more than 0.5m, basic can meet the demand of the support strength; (3) buried depth is more than 50m, should undertake special technical design, determine the tunnel support scheme and parameters.

5. Secondary Lining and Timing Analysis

Sandy pebble since the stability of surrounding rock ability is poor, the traditional secondary lining applied time no longer applicable, from the point of control deformation of the secondary lining applied for the earlier vault subsidence and horizontal convergence is smaller, but will cause the secondary lining share more load, even by strengthening reinforcement meets the demand of strength, but is still likely to result in the crack of the concrete [10]. Reasonable secondary lining and timing should be both control the deformation and load points but request, through calculation analysis and study can be applied to determine the secondary lining for timing, constraints respectively consider secondary lining behind it is 2m, 4m, 6m, 8m, 10m, etc. 4 kinds of circumstances.

5.1. Primary Support Subsidence

Vault subsidence constraints with the secondary lining backward down the steps of maximum distance increases. with the increase of distance from 2m to 6m, vault subsidence increase amplitude is small, when the distance constraints backward down the steps of the secondary lining after more than 6m, vault subsidence speed up the growth rate.

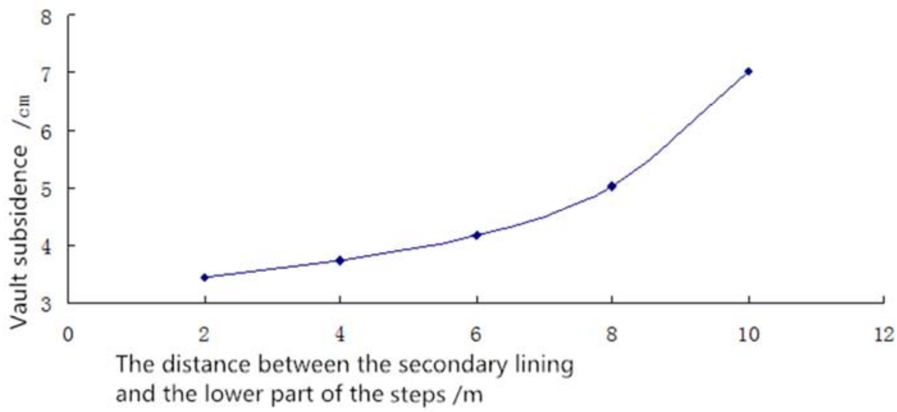

Figure 13. *Vault subsidence and the secondary lining follow up time relationship.*

5.2. The Secondary Lining Stress

The initial support of the principal stress with secondary lining backward down the steps and decreased the distance constraints. In the process of distance from 2m to 6m, the minimum principal stress reduced by 24%, the maximum principal stress reduced by 42%, When the secondary lining backward down the steps of the distance constraints after more than 6m, principal stress value basically unchanged.

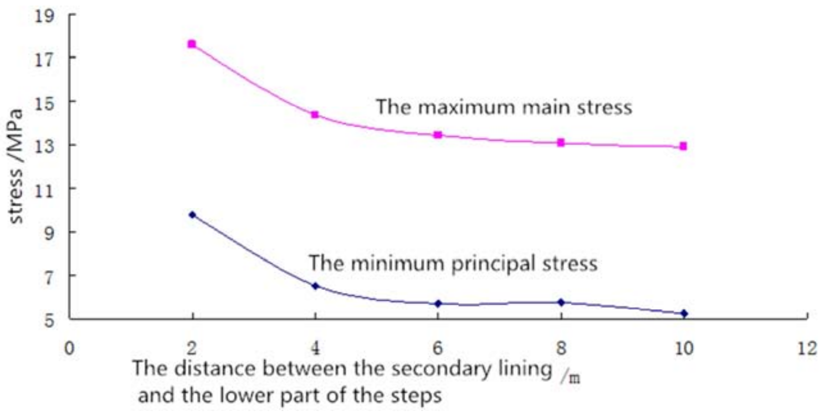

Figure 14. *Secondary lining of principal stress and the secondary lining follow up time.*

5.3. Make Time to Determine the Secondary Lining

Comprehensive analysis of the initial supporting vault sink, lining applied stress and the secondary lining for timing relationship can be seen that Secondary lining backward down the steps of the distance constraints is equal to 6m is vault subsidence and the turning point of principal stress change rate. Distance of more than 6m can cause excessive settlement, while less than 6m can cause lining stress too big. So, secondary lining and timing constraints can be identified as backward down the steps it 6m.

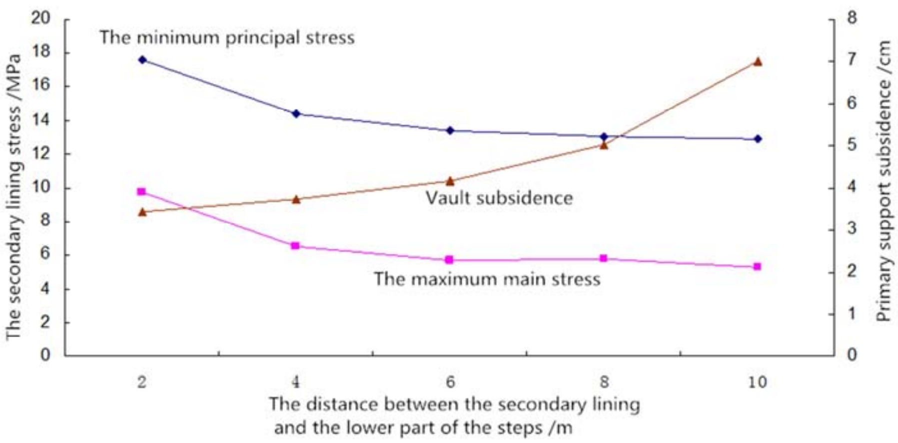

Figure 15. *Secondary lining follow up time comprehensive comparison.*

6. Conclusion

In the process of highway tunnel construction, often through complex geological environment and produce some tunnel disaster, such as large deformation of surrounding rock, landslide, etc. Not reasonable parameters of supporting structure is one of the key factors leading to these disasters, therefore, in the process of tunnel construction, supporting structure mechanical properties research is very meaningful.

Based on the construction of the qinghai eastern region following long high-speed through the gongboxia sandy pebble on tunnel engineering, by means of $FLAC^{3D}$ numerical analysis software, using theoretical analysis, numerical simulation and calculation of supporting structure based on the theory of the load structure for the research methods of loose sand pebble tunnel in the construction process of the initial supporting structure and the second lining do timing system research on the mechanical behavior such as shi, mainly the following two results:

Study the sandy pebble tunnel primary support stiffness and strength characteristics, the influence of early sandy pebble tunnel supporting parameters Suggestions: buried depth is less than 35m, early bolting arch model should not be less than I22b, thickness of sprayed concrete desirable 28cm, arch span should not be more than 0.5m, can meet the need of the support strength. Buried depth is more than 35m, less than 50m, early bolting arch model should not be less than I25b, thickness of sprayed concrete desirable 32cm, arch span should not be more than 0.5m, basic can meet the need of the support strength. Buried depth is more than 50m, should undertake special technical design, determine the tunnel support scheme and parameters.

The second lining and the timing of mechanical impact characteristic, proposed Secondary lining backward down the steps of the distance constraints is equal to 6m is vault subsidence and the turning point of principal stress change rate. Distance of more than 6m can cause excessive settlement, while less than 6m can cause lining stress too big. So, secondary lining and timing constraints can be identified as backward down the steps it 6m, about 1/2 span tunnel.

About mechanical behavior of tunnel support structure, i will consider the tunnel rock mass structure and its effect on the rheological, establish the viscoelastic plasticity model is set up simulation supporting structure in the process of tunnel construction mechanical behavior in the future, which might be the research direction of highway tunnel supporting structure mechanical behavior.

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