International Journal of Smart Home
Vol. 10, No. 7 (2016), pp. 69-80
http://dx.doi.org/10.14257/ijsh.2016.10.7.08

Study on Stabilit of Surrounding Rock in Deep Tunnel and It's Support Design in Donghai Mine

JIN Zhupeng[1,2], ZHANG junwen[2], LI yulin[2]

[1.] *China University of mining and Technology (Beijing), Beijing 100083;*
[2.] *Heilongjiang university of science and technology Harbin150027,China;*
842533837@qq.com

Abstract

In order to control the deformation of surrounding rock in deep mine and study the corresponding patterns, the determination of its mechanics parameters and property, numerical simulation and the design of support scheme on the surrounding rock in fifth mining area of Donghai mine are conductive to the study of effective control of deformation and failure. By analyzing the characteristics of deformation and failure of surrounding rock, its regularity and corresponding reasons are finally found—— high stress make rock soft and lead to the large deformation of surrounding rock, which inevitably contribute to the broken roof and heaved floor. In addition, based on the numerical simulation, we further analyze the stress distribution and deformation characteristics of surrounding rock and proposed the anchor- injection - net – cable, the double support scheme. We also came up with the whole sealing and coordinated supporter for the fracturing roadway of large deformation, especially in the intersection roadways, witch undoubtedly is beneficial to the research of deformation mechanism and control of surrounding rock in deep mine.

Keywords: *Deep mine; surrounding rock of roadway; stress state; support scheme*

.1 Introduction

Surrounding rock deformation and failure is not only one of the main problems in deep mining researches, but also the core content of surrounding rock control and supporting technology in deep mine roadways [1-6]. The engineering related in soft rock roadway has been wildly conducted and deeply studied in many European countries including former Soviet Union, Germany, Poland, and some American countries, such as the United States, Canada, as well as South Africa. Although they have made some achievement in new supporting materials and equipments, the research on the deformation of deep surrounding rock, the geological patterns and the softening of deep rock has just started [7-9]. Xie Heping and others applied The Fractal Theory to the development of rock joints and fractures in the roadway, and the dynamic phenomenon of coal and rock, which to a certain extent reveals the inherent mechanism of the failure of the roadway surrounding rock [10-11]. Qian Qihu, Zhou Xiaoping, and others did sufficient researches in the response of deep tunnels and finally established The strength criterion of deep rock. Apart from those, they also contributed to the analysis of the form of deep tunnel excavation and surrounding rock failure, which helps the study about the failure process and mechanism of surrounding rock in deep tunnels [13]. By means of computer tomography (CT), research on the mechanism of rock and soil damage was conducted on a micro scale by Ge Xiurun and etc. The damage mechanism of various rock and soil is classified by macro and micro experimental study, while the damage evolution equation as well as constitutive model of rock and soil can be established [14].

ISSN: 1975-4094 IJSH

According to the former research results, the main reason for the failure of deep well is the disharmony between the high stress state of surrounding rock and the stress redistribution caused by the excavation. After entering the deep stage, the roadways experience some huge changes, such as the softening of surrounding rock, the rise of temperature and larger deformation, which undoubtedly make the roadway supporting much harder and pose a threat to safety in coal mining enterprises. This is especially true when we consider the fact that increasing number of mines in China start to be a member of the deep mining. Therefore, the research on the deformation and failure of the roadway in deep mine and the corresponding supporting design are of a great importance. It will also be one of the main direction of future researches on the surrounding rock of roadways [15-17].

Via the analysis and summary for the deformation and failure rules of roadway surrounding rock in the fifth mining area of East China Sea mine, a typical deep mine, we are able to determine the main factors which impact the deformation as well as failure and locate the key deformation part. At the same time, through the determination of its rock parameters and its corresponding engineering background, we also implement the numerical simulation and supporting designs. In order to ensure the sufficient release of elastic energy in surrounding rock of the mountain tunnels, we came up with the specific supporting scheme, which was also beneficial to the full use of self bearing capacity of surrounding rock, the coordinating deformation of surrounding rock and the its stability.

2. Geological Background

East China Sea area is a typical deep mine whose tunnels in its fifth mining area located in underground, lower than -1000m. The temperature in this area reached 37.1 ~ 38.0 degrees. The research of broken roadway section average temperature reached 37.8. The roadway in this area is characterized by large deformation and softening of rock, which provides a good model for the study of deep rock mass.

The East China Sea mine headed from to northwest to northeast with the dip angle of 15 degrees to 60 degrees. In addition, this area was impacted by igneous rock and the squeezing pressure from the northern and Southern areas. Various distance between the coal bearing strata and the rigid base plate impel different formation dip angles and the structural complexity. However, faults played a pivotal role in this situation, including F48 (a eastern fault near the boundary from NW20 degrees - NE5 degree), F49 (a northeast fault of NW75°) , F501 (a western boundary fault from NW10°to NE20°) and 32# (a group of faults of NW61°under -600m with a drop of 0.8 - 3.9m).

3. Characteristics of Surrounding Rock of Roadway and Its Mechanical Properties

3.1 Main Failure Characteristics of Roadway Surrounding Rock

Through the field investigation, analysis and summary, the typical characteristics of the surrounding rock failure in the roadway section (two horizontal section) are obtained:

(1) Broken roof of the tunnel

The rock layer in the roadway is mainly composed of silt and mixed with multiple layers of shale. The rock joints are developed and the strata are evident [12] under the current high stress state. Due to the effect of high stress and disturbance, the roof rock in the tunnel appears to break off and most of the bolts start to become invalid.

(2) Huge deformation of two sides in roadways

Under the high pressure of surrounding rock, the deformation of the two sides in deep mine was much bigger than shallow area. At the same time, surrounding rock formed a certain angle with the main direction of roadway and fail along the bedding with about 90 degrees. The distance of fractures was large among which the maximum can reach more than 30cm. the repair rate in these roadways was also large and the effect is not obvious.

(3) Floor heave of roadways

The situation of floor heave in this area is quite serious and some of them could reach to 1m above, witch had caused the orbital bulge and had an huge impacts on the normal production of this mine. As shown in Figure 3, in the process of tunnel construction, the speed of floor heave varies----- the maximum speed belongs to the very beginning of excavation and it gradually slows down with slight fluctuation.

Figure 3.The Floor Heavein the Downhill Tunnel

(4) The failure of support

Most rock guniting layer in Roadway are shed; brickwork layer seriously is damaged; most bolt and cable anchor do not work; local bolt and cable anchor are pulled off [12]. Because of the large deformation of the surrounding rock, the insufficient contact and the local large stress in roadways , retractable metallic supporter can be badly deformed and become invalid.

(5) Temperature and dynamic response of surrounding rock in tunnel

The temperature of the surrounding rock in deep roadways reached to 37.8 degrees and there were some obvious dynamic response phenomena too.

Although the East China coal mine had carried on the roadway maintenance for many times, the maintenance effect was still poor and the cost was very high. In some roadways with serious 7surrounding rock failure, lots of the anchor cables mistakenly used as bolts and arranged at a row distance of 1.0m. However, in the fifth mining area, some roadways and chambers were still unable to repair, such as the substation area, mining area of upper yard and track down the mountain top, which caused the re-excavation of roadway in order to maintain production.

3.2 Determination of Rock Mechanics Parameters

Before the measurement of in-situ stress, its related mechanical properties are needed to grasp. Therefore, according to its geological situation, especially in the fifth area where the surrounding rock damage is severe, test and analysis of the index were carried out to gain the corresponding mechanics parameters, such as, the uniaxial compressive strength of rock, uniaxial tensile strength, elastic modulus, Poisson's ratio and so on.

In the samples of 18 groups, the main proportion of rock is powder sandstone mixed with a small amount of siltstone. We also obtain that the uniaxial compressive strength test of rock generally was 48.88 ~ 100.94MPa and uniaxial compressive strength on average is 75.40MPa. In addition, elastic modulus of the rock usually is 11.49 to 18.82GPa; average elastic modulus is 15.78GPa; deformation modulus is 600 ~ 15.28GPa; average deformation modulus is 10.92GPa; Poisson's ratio is 0.16 ~ 0.57; average Poisson's ratio is 0.30.

The basic mechanical parameters of rock compressive strength, elastic modulus, Poisson's ratio and other basic mechanical parameters are obtained by processing the data of tensile, compression and shear tests respectively[12]. The final mechanical parameters are as follows:

Table 1.The Statistical Table about the Rock Layered Compression Test Data

Layer number	#35 Roof	#35 Floor	#35 Two-side
compressive strength（MPa）	67.561	76.895	87.41
elastic modulus（GPa）	15.886	15.216	17.692
modulus of deformation（GPa）	9.692	12.405	14.938
Poisson's ratio	0.236	0.302	0.286

It can be clear seen from experimental results that the compressive strength of the surrounding rock obviously increased. The roof and floor was not intact and the deformation of the roadway was large because of the high ground stress, although the rock strength and hardness is incredible.

4. Numerical Simulation

The main failure modes of the fifth mining section in Donghai Coal Mine are the layered fracture of roof, the extrude of tunnel walls to the roadway, floor heave, the failure of roadway support, the high speed of deformation at the initial stage, the temperature of surrounding rock and dynamic response. we use numerical simulation software to analyze the distribution of surrounding rock stress and it corresponding deformation, witch helps the study of rock deformation and failure mechanism and is beneficial to the determination of supporting parts, supporting method and construction method.

According to the experimental data in the roadways, the parameters of surrounding rock are as follows: Young's modulus (16.4GPa), Poisson's ratio (0.3), the bulk density（$2.6\mathrm{t/m^3}$）, Internal friction angle($36°$) and cohesive force(0.82MPa). The uniaxial compressive strength(75.4MPa) was obtained according to the experimental values. At the same time, the thermal expansion coefficient is3.87×10^{-7}; the thermal diffusion coefficient is 1.8×10^{-3}; the temperature gradient is$3°/100\mathrm{m}$; The temperature is $37.8°$; the heat conduction coefficient is 0.82; the surface temperature is $20°\mathrm{C}$. Because of the inherent difference of the laboratory conditions and the real situation, after being calculated by reduction coefficient of the internal friction angle(0.854-0.90) and cohesion(0.20-0.30), the internal friction angle and cohesion of rock are needed to be converted to 0.87 and 0.25 respectively. Via the new Hoek-Brown criteria (*e.g.*, type 1), the parameter of M is 1.231and the range of s is from 18 to 20.

$$\left.\begin{aligned} \sigma_1 &= \sigma_3 + \sqrt{m\sigma_c\sigma_3 + s\sigma_c^2} \\ \sigma_{tmass} &= \frac{1}{2}\sigma_1\left(m - \sqrt{m^2 + 4s}\right) \\ \tau &= A\sigma_c\left[(\sigma_n - \sigma_t)/\sigma_c\right]^B \end{aligned}\right\} \quad (1)$$

Among the Hoek-Brown criteria, σ_1 and σ_3 represent the maximum and minimum principal stress; σ_c stands for the uniaxial compressive strength of rocks; σ_{tmass}, however, is the tensile strength; σ_n and τ are used to describe vertical effective stress and shear stress. In addition, m, s,A and B are experimental coefficient. The hardness of rocks is evaluated by m whose range is between 0.0000001 and 25.the parameter, s(0 ~ 1), is used to reflect the fragmentation degree of rock. The value of A and B can be gained from The simulation process is shown in Figure 4 ~ 7.

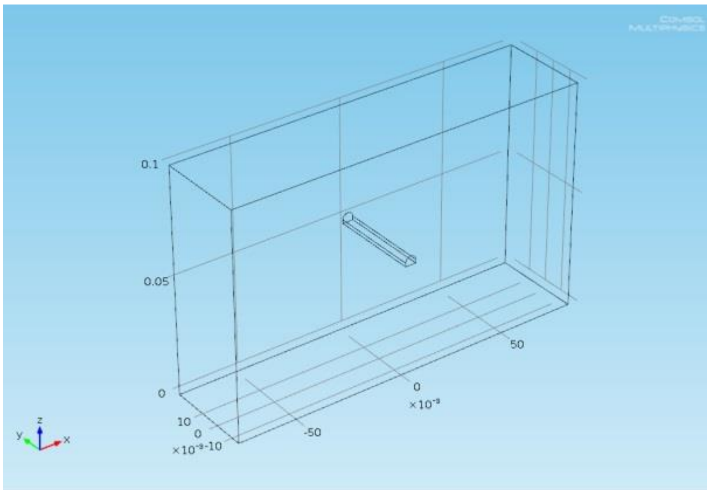

Figure 4.The Spatial Structure of Tunnel and Rock Charts in the Model

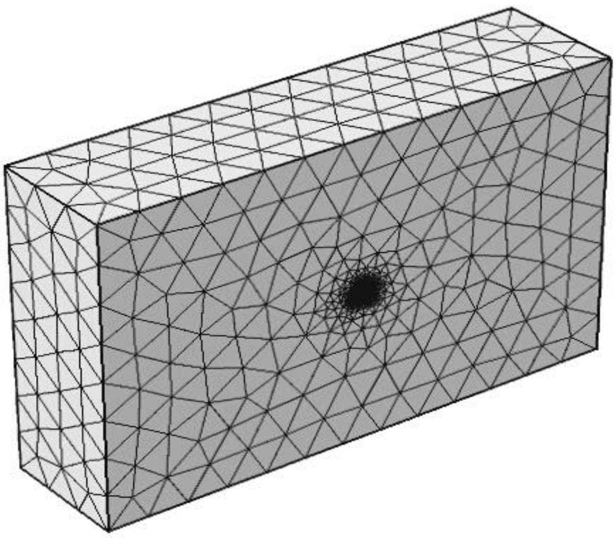

Figure 5. The Roadway Mesh

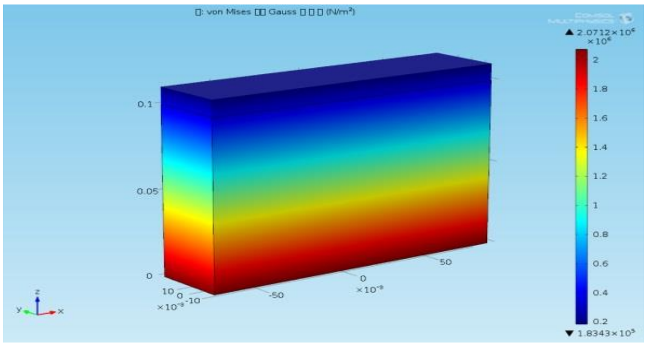

Figure 6.The Stress Distribution before Excavation of Rock the Excavation of Roadway

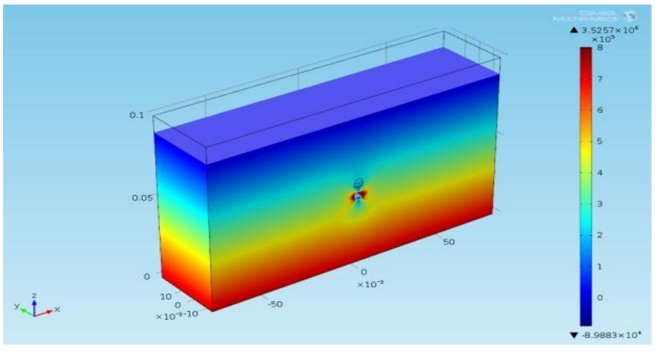

Figure 7.Rock Stress Distribution after the Excavation of Roadway

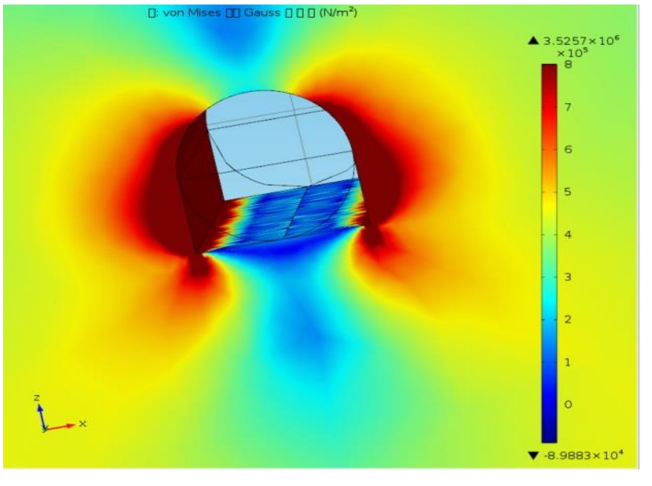

Figure 8.The Stress Distribution after the Excavation of Roadway Surrounding

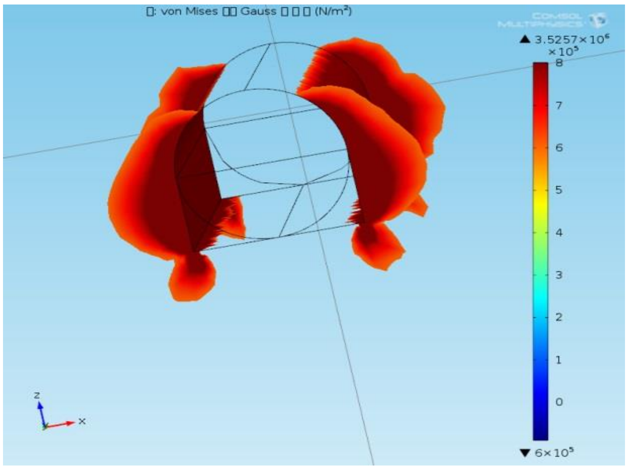

Figure 9. After the Excavation of Roadway Rock Support of Key Parts

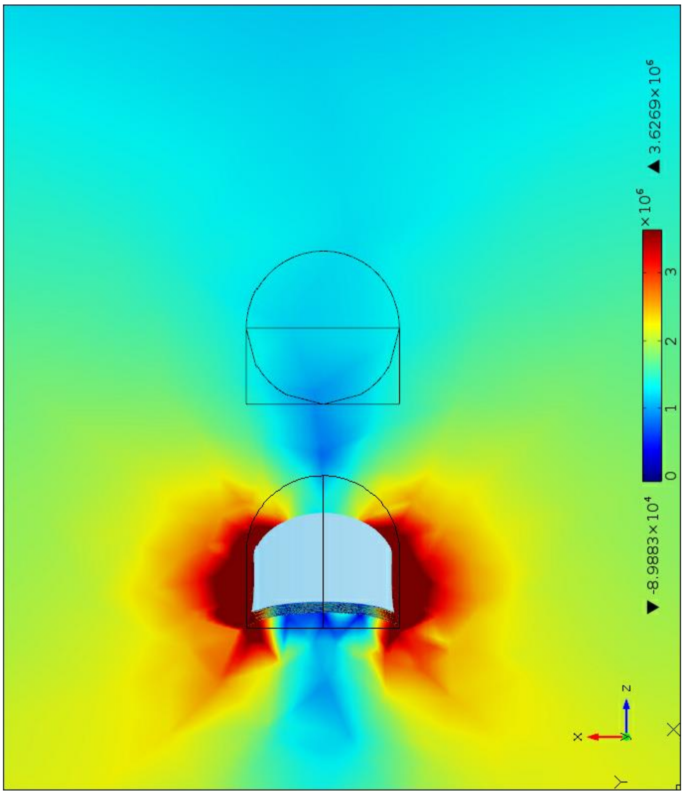

Figure 10.The Deformation of Surrounding Rock after Excavation

In the Figure 8, although the cross section of roadway is a semicircular arch, its analysis of surrounding rock stress and stress distribution are basically consistent with rectangular roadway. Through the deformation analysis of surrounding rock in Figure 8 and Figure 10, it can be clearly seen that the two sides and bottom in roadway appears the great stress concentration after the tunnel excavation; roof and floor appeared great tensile stress concentration, which directly led to the huge displacement in two sides. Apart from that, the roof and floor mixed with a small amount of siltstone appeared large tensile stress. Therefore, it is inevitable that the surrounding rock go through serious floor heave, increasing displacement of two sides, broken roof and other related rock deformation failure. Figure 9 shows the key parts of the surrounding rock support .the main pressure lies in the red part of the stress zone; the blank part surrounded by rock is the tension stress concentration area, which provides a critical reference value for the study of supporting measures, supporting for the key parts and its corresponding parameters.

5. Supporting Design and the Selection Parameter

5.1 Support Scheme

According to the characteristics of surrounding rock deformation, surrounding rock conditions, the analysis of the crack evolution law and the numerical simulation analysis, the detail for the choice of the roadway is shown in Figure 11.

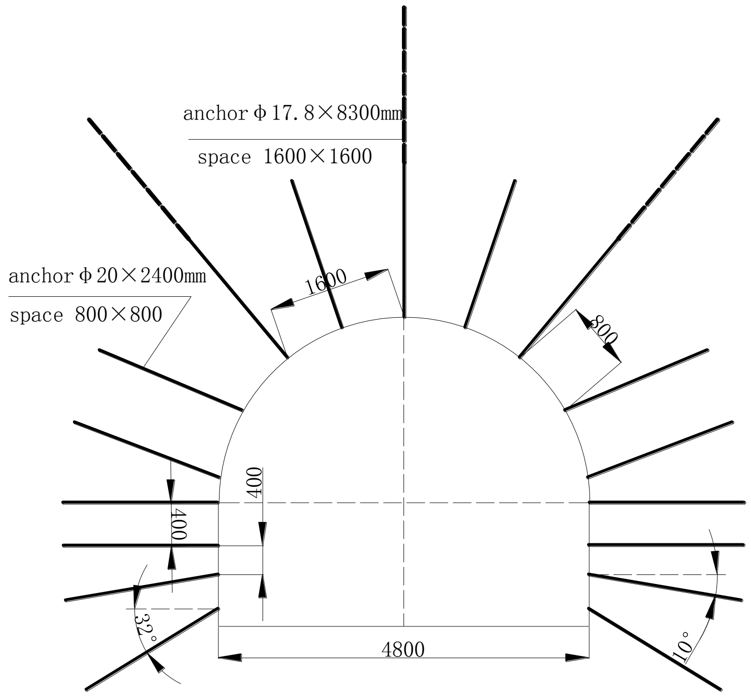

Figure 11. The Support Design for Roadway

According to the characteristics of stress distribution in surrounding rock, the circular roadway is more favorable to preventing the deformation and stress concentration. Therefore, in the intersection of the roadways, especially in the extremely broken and complex section, a special form of support, the whole sealing and equivalent stress bracket, is indispensable. This supporting design lead to the equivalent distribution of stress in surrounding rock. Under this circumstance, its self bearing capacity can be fully utilized and achieve the best supporting effects. In addition, the special support form can be coordinated with deformation according to different situation, witch plays a vital role in the release of the energy stored in surrounding rock. The form of the main body is shown in Figure 12.

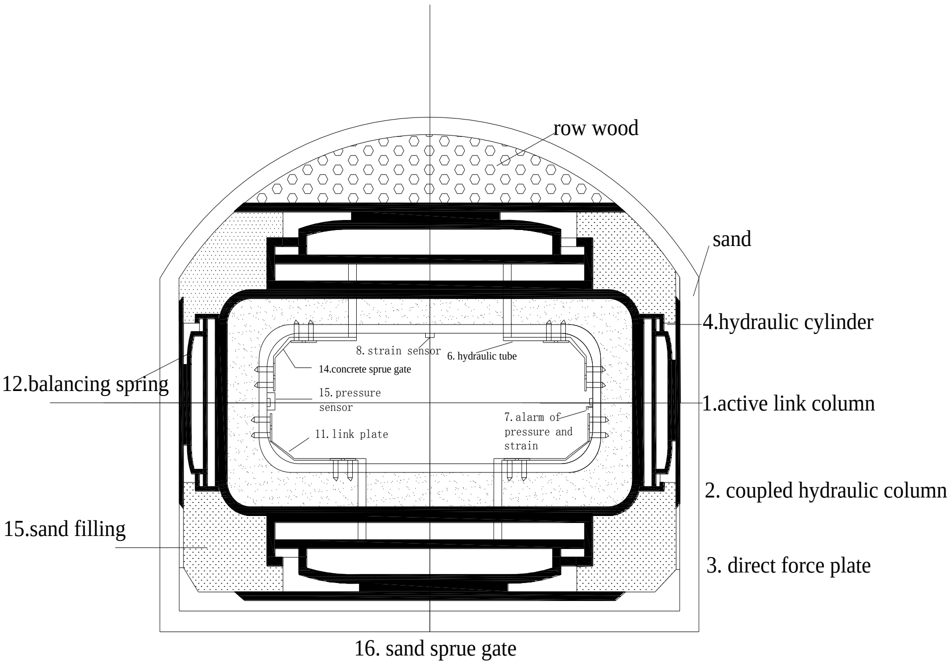

Figure 12. Whole Sealing and Isostress and Coordinated and Transmutable Supporter

In the Figure 12, (1) is the fixed connection between the active link column and the direct force plate. And the balancing spring is set up between the hydraulic cylinder and the pressure plate. (2) for the support frame, the pressure is set up. (3) is the pressure and strain alarm above the supporting frame. (4) stands for the pack hole around 4 corners in the supporting frame. (5) represents the supporting frame composed of an outer metal frame, an inner metal frame with concrete sprue gate and a concrete frame. (6) is so called inner metal frame made of top right bottom and left side of frame. (7) represents a direct stress plate set with finite support column . (8) is the coupled hydraulic column attached with reinforcing material layer.

The realization way is explained as follows. The upper and bottom of the supporting frame is set with the hydraulic cylinder connected with the hydraulic tube. Every piston of the hydraulic cylinder is directly linked with the coupled hydraulic column with spherical end surface. The outside of the coupled hydraulic column is wrapped by direct stress plates jointed with articulations. In spherical end surface intersected by coupled hydraulic column and articulation, the bottom of each hydraulic cylinder and the supporting frame is provided with a pressure sensor and a strain sensor respectively.

The support technology scheme taking alloy steel, concrete and sand as the raw material designs an active force plate among which automatic coupling is capable of creating the corresponding energy release space. The design of the hydraulic device plays a pivotal role in maintaining the uniform stress around supporting facilities, witch not only can improve the overall structure of the supporting effects, but also encourage the further release of surrounding rock energy. Under these circumstances, the pressure of surrounding rock can be reduced and the supporting effect can get much better. The pressure and strain sensors placed in the key position are able to monitor surrounding rock pressure and to support give warning before the failure. According to the change of the surrounding rock pressure, the timely bolt-anchor-cable grouting support can enhance the strength of the surrounding rock to prevent further expansion of the cracks in 3 to 5 days. Through the analysis and comparison, this new model can achieve the purpose of preventing and controlling bottom heave, the roof subsidence ,the displacement of two sides and the impact pressure of the coal mine.

5.2 The Selection of Parameters

Combined with the characteristics of deformation and failure in roadways, the rock mechanics parameters of surrounding rock are determined by means of numerical simulation. Through the analysis of stress distribution of the surrounding rock and other factors, the final supporting scheme is bolt-anchor-cable grouting support. The supporting in first time is mainly the anchor injection of 100mm; The support in second time, however, is the anchor injection of 210mm accompanied with net of 210mm.

(1) **Criterion for anchor:** the diameter of anchor should be 20 x 2400mm; The standard space between bolt rows is 800 * 800mm; The length of bolt anchorage is 1200mm (fast or medium anchorage agent for each volume). Bolt should be hit in the stubble of web pressure.

(2) **Criterion for metal mesh:** the mesh is made of the diameter of 5.6mm cold drawn steel mesh of 100 * 100mm; the amplitude is 900 * 1700mm; the lap length between meshed is 100mm; the wire 14# placed every 100mm is used for tying connection and the connection points are evenly arranged.

(3) **Criterion for anchor:** the standard form is 17.8 * 8300mm steel strand with a space of 1600 x 1600mm; the length anchorage is 2400mm.

(4) **Criterion for anchoring agent:** every anchor uses one Z2360 and K2360 resin anchoring agent and each root consume two Z2360 and K2360 resin anchoring agent.

6. Conclusions

Combining with the specific conditions in the fifth mining area of Donghai coal mine, we carry out the physical mechanics test of rock and analyze the properties of the surrounding rock. On the basis of numerical simulation and support design, we came up with the corresponding design and drawn the following conclusions:

(1) Due to the high stress and temperature in this mining area, the mechanical strength of rock tend be disappointing. In this case, a great deal of broken rock and large deformation in the roadway are likely to come into being. At the same time, the compressive strength and tensile strength remain in a lower state, which certainly is not conducive to supporting.

(2) According to the deformation regularity and characteristics of surrounding rock in deep mine as well as numerical simulation for the stress distribution in semi-circular arched tunnel, the key support parameters the anchor-injection-net-cable secondary support method are finally determined. This supporting method can effectively reduce the tensile stress of the roof and floor, exert the self bearing capacity of the surrounding rock and reduce the deformation and failure of the surrounding rock to the greatest measure.

(3) The whole sealing iso-stress and coordinated supporter is utilized in the intersection of roadways and somewhere with serious broken rocks and large deformation. In addition, the effects of controlling the deformation can be much better with the connection between bolt and grouting during the secondary support.

Acknowledgements

The authors wish to acknowledge the funding support from Fund Project: The National Natural Science Fund（51574114，51474099）

References

[1] Xie Heping. The development of coal science and technology in [J]. coal journal, 1997, 22 (by):10-17.
[2] Peng Suping, Tong is virtuous, Li J C, *etc*.. Geological disasters in coal mining in eastern China and the future research direction [C]. The sixth session of the conference of the national mining the set, 1999:141-144.
[3] Xie He Ping, Gao Deli. China's energy development trend and energy science and technology prospect [C]. China Association for science and technology the third Youth Academic Conference: and sustainable development of resources and environment science and technology. Beijing: China Science and Technology Press, 3-7.
[4] Peng Suping. The establishment and perfection of our country coal mine geological security system of high yield and high efficiency coal mine several problems [R]. China Association for the 31 "forum of young scientists" Proceedings of the. Beijing: China Coal Industry Publishing House 1998:19-25.
[5] Zhou Guangzhao. Four [M]. Beijing: China Science and Technology Press, 1998:554-558.
[6] Qian Ming, Liu Tingcheng. Mine pressure and control [M]. Beijing: Coal Industry Press, 1996.08.
[7] Jin Hu song, Gong Ling Hui, Ma Yuan. Deep roadway support different support form the comparative calculation and analysis [J]. Mining and metallurgical engineering.2010.08, 34 (4)
[8] Sun Shujuan, Wang Lin, Zhang Dunfu, Wang Hanpeng. Analysis of the time history response of rock mass in deep tunnel excavation [J]. Journal.2011.05, 36 (5):738-746.
[9] Gong Ling Hui, Jin Hu song, Jing Hong Wen. Based on the progressive failure of surrounding rock in deep tunnel bearing structure evolution analysis [J]. Metal mines settings (5):44-48.
[10] Yang Jun, Sun Xiaoming, Guo Zhibiao. Research on the key technology of coupling support in deep soft rock roadway [J]. coal support.2009 (1):17-22.
[11] Xie Guangxiang. Deep roadway surrounding rock mechanics characteristics and stability control [J]. Journal of China Coal Society.2009.07, 36 (7):881-886.
[12] He Manchao, Xie Heping, Peng Suping, Jiang Yaodong. Research on rock mechanics in deep mining [J].:2803-2813., 24 (16).2005.08
[13] Qian Qihu. Response of deep rock mass engineering characteristic scientific phenomena and "deep" definition [J]. East China Institute of technology.2004.03. In 27 (1):1-5.
[14] summ, Ren Jian Xi, Pu Yi Bin, Ma Wei, Zhu Yuanlin. Jointed rock unloading injury damage process of CT real-time detection [J]. Rock and soil mechanics.2002.10, of 23 (5)
[15] Zhang Wei, Liu Wei, Chen Shihai. Research on the rupture range of the deep rock roadway blasting unloading in the Journal of Shandong University of Science and Technology (NATURAL SCIENCE EDITION).2013.04, 32 (2).
[16] Sun Xiaoming, he ManChao, Zhang Guofeng, Cai Feng. Hebi 5 deep high stress soft rock roadway destruction mechanism and countermeasures [J]. Liaoning Engineering Technology University Journal (NATURAL SCIENCE EDITION).2009.06 28 (3): 393-396. Chinese with abstract in English.
[17] Sun Guangyi. Study on the complexity of surrounding rock and support system of mine [J]. Journal of Heilongjiang Institute of Science and Technology,.2010.03, 20 (2): 97-102.
[18] He Manchao. in the deep rock mechanics and rock mechanics.2005.08 Journal of mining engineering research, 24 (16): 2803-2813.
[19] Zeng Xin Zhao. With interbedded halite nonlinear differential deformation analysis and Research on the stability of storage [D]. Tianjin: Hebei University of technology.2011.05.
[20] Zhao Yu. Based on higher order theory of composite structure calculation method [D]. Shenyang: Shenyang University of Aeronautics and Astronautics.2012.11.
[21] Wang Chenghu, he ManChao. Hoek brown rock mass strength estimation method and its engineering application [J]. Rock mechanics and Engineering Journal of.2010.09 29 (2) 4077-4081.