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The migration law of overlay rock and coal in deeply inclined coal seam with fully mechanized top coal caving

Jian Liu[1], Shan-le Chen[1,2], Hua-jun Wang[2], Yu-cheng Li[1] and Xiaowei Geng[1]
[1]College of Safety Science and Engineering, LiaoNing Technical University, Liao Ning FuXin-123 000,China
[2]College of Mining Engineering, Guizhou University of Engineering Science, Gui Zhou BiJie-551 700,China
*Corresponding Author's Email : lelechen131452@163.com

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Abstract

In a mine area, some environment geotechnics problems always occure, induced by mined-out region such as the subsidence and cracks at ground level, deformation and destruction of buildings, landslides destruction of water resources and the ecological environment. In order to research the migration of surrounding rock and coal in steeply inclined super high seams which used fully mechanized top coal caving, a working face of a certain mine was made as an example, analyzed the migration law of the overlay rock and coal under different caving ratio of fully mechanized top coal caving with numerical simulation analysis. The results suggest that the laws of overlay rock deformation caused by deeply inclined coal seam were different from horizontal coal seam. On the inclined direction, with an increase of dip angle and caving ratio, the vertical displacement of overlay rock and coal became greater, the asymmetric phenomenon of vertical displacement became obvious. On the trend direction, active region and transition region in goaf became smaller along with the increase of mining and caving ratio. On the contrary, the stable region area became greater. Therefore, there was an essential difference between the mechanism of surface movement deformation with deeply inclined coal seam and that with horizontal coal seam.

Key words

Fully mechanized top coal caving, Migration law, Mining and caving ratio, Numerical simulation

Introduction

The complexity of geological and mining conditions when working seam will overburden the overlying strata which will lead to surface movement and deformation going so far as to fracture and fold in the hills. Another situation will cause non-continuous destruction. Such a problem is particularly obvious in inclined coalmining. This situation is further gradually exacerbated by coal seam dip angle and depth. The surface deformation, caused by mining and surface construction damage, is becoming a problem. This is drawing more and more attention to underground coal mining causing surface deformation (Zhang 2013; Wang 2005).

Ecological restoration to mining area land, industrial land, residential land and administrative land, the needs of park land require overall planning. Angle (great inclination angle) research in the process of surface deformation caused by coal mining is necessary. Due to the effects of underground coal mining , roads, ground surface buildings, and cultivated lands are adversely affected. The underground mining poses a threat to the surrounding residents' daily life. Therefore, an internal and inherent study of the influence of mining deeply inclined coal seam on surface movement and deformation is needed in order to achieve qualitative evaluation and management through objective law.

In China, the recoverable reserve of thick coal seam is 45 % of the total proven coal reserves. Half of the total coal production is from thick coal seam. After more than 20 years of exploration and experimentation, the technology of fully mechanized top coal caving in gentle dip thick coal seam was formed gradually. Fully mechanized top coal caving is more and more being applied to the steep dip coal seam with consideration for the geological conditions and mining technology. Fully mechanized top coal caving is a mining method, combined with high fall ore method and longwall coal mining method. Fully mechanized top coal caving in steep dip coal seam is a shorter longwall working face, arranged along the horizontal section at the bottom. Then, the cracked coal on the top is released behind the working face, because of rock pressure or human behaviors (Xu, 2009).

Relative to the fully mechanized level by level method, the fully mechanized top coal caving has the advantage of high yield and high efficiency. The low rate of roadway driving, little moving of the working face, the cost of attaining tons of coal is low and well-adapted to the geological conditions (Meng *et al.*, 2009). However, a series of problems may arise, such as gas control, roof control, percentage recovery and fire protection in goaf (Wang *et al.,* 2008; Wang, 2005). To address the problems mentioned above, scholars have performed extensive research. The underground high precision microseismic monitoring system has been used to analyze the rock movement in top-caving working face in extra-thick coal seam. The law of gas emission was studied as well (Jiang *et al.,* 2011). Top-coal caving is key factor affecting the efficienc of production at thick-coal seams (Yasitli *et al.,* 2005). On the basis of analyzing coal loss in fully mechanized caving of thick seam, some methods for increasing the recovery rate of fully mechanized caving mining in flat seam were discussed by FAN (Fan 2010). The fire in goaf is a disaster in coal mine, especially in ultra thick seam. Air leakage and pressure were the main factors for coal spontaneous combustion at high caved area (Ren *et al.,* 2007). The essence of those questions is stratums' movement, deformation and breaking (Wen *et al.,* 2014; Honkanadavar *et al.,* 2014). After the coal seam has been caved in top-caving working face, the rock's movement should be a primary factor.

The mining and caving ratio is an important factor in fully mechanized top coal caving, which affects the movement of gas and destruction principle of overlying rock. There are many methods to solve this problem, such as theoretical analysis and field monitoring. With the development of numerical calculation mothod, the numerical simulation is more and more used in various fields of engineering application. In mining field, the FLAC/FLAC3D, FLUENT, UDEC/3DEC and Matlab are used to analyze the problem (Wang *et al.,* 2013; Wang *et al.,* 2013a). In the present study, investigate was carried of find out how the mining and caving ratio affected the movement principle of the surrounding rock and coal using the FLAC3D to build the numerical simulation model. When mining and caving ratio was 1:1, 1:2 and 1:3, respectively, how fast could the rock and coal seam move?

Materials and Methods

Study sites: Xigou coal mine is located in East of Urumqi city in Sinkiang Province, China. No.A4 coal seam is the main mining seam in the Xigou coal mine. The dip angle of No.A4 coal seam ranges from 42° to 54°, the average thickness of No.A4 coal seam was 32 m. Native fissure of the coal seam was middle development, and the firmness coefficient was less than 3. The feature of coal seam is shown in Table 1.

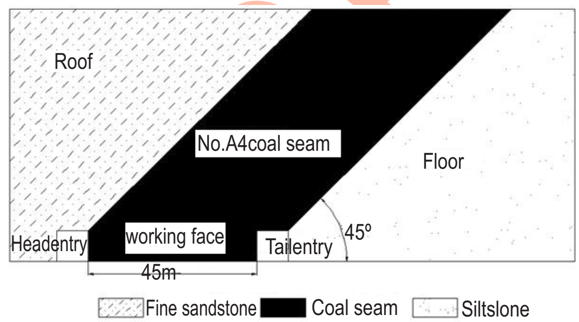


Fig. 1 : The profile of Working face

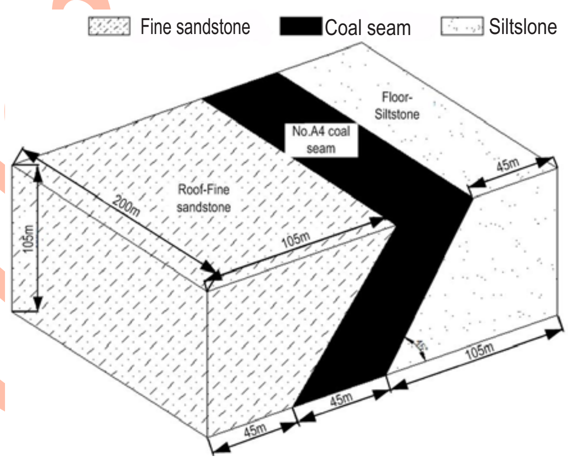


Fig. 2 : The geometry model

Table 1 : Characters of Coal Seam

Coal Seam	Thickness/m	Spacing/m	Structure	Stability	Workability
A4	28.65-36.87 32	20-30	Simpleness	steady	all can be recoverable
A5	1.9-2.472.19(5)		Simpleness		all can be recoverable
		5-60	Simpleness	steady	
A6	0.45-2.13(4)		Simpleness		parts can be recoverable
		8-13	Simpleness	unstead	
A8	0-1.07(2)		Simpleness	unsteady	unrecoverable

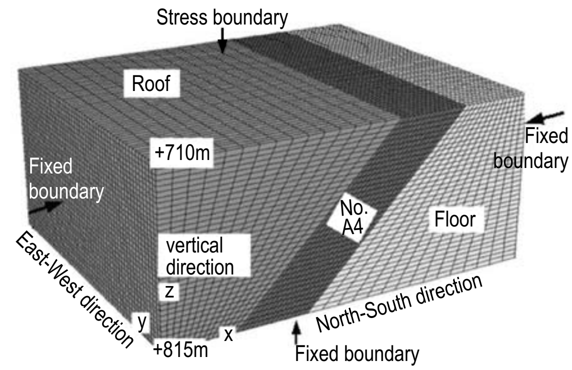
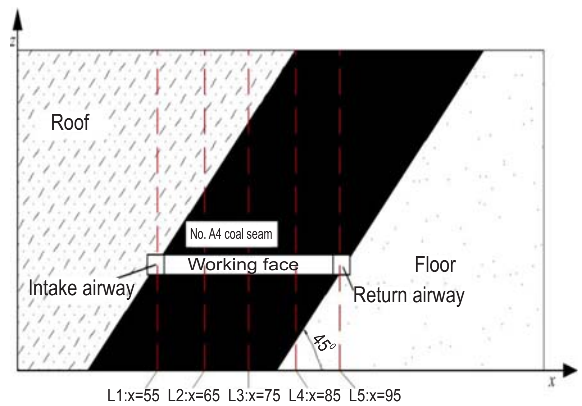


Fig. 3 : The grid of model



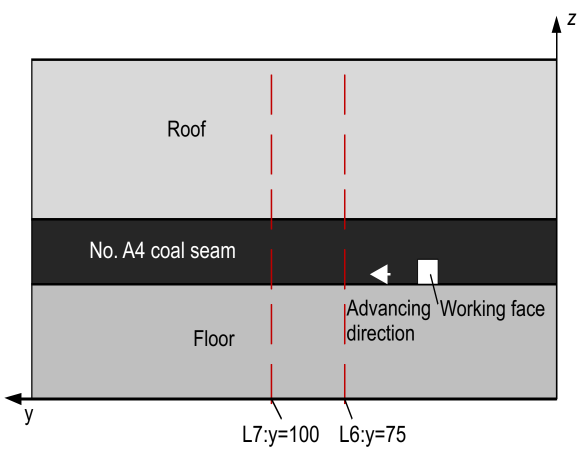


Fig. 5 : Observation lines in section B (x=55 m)

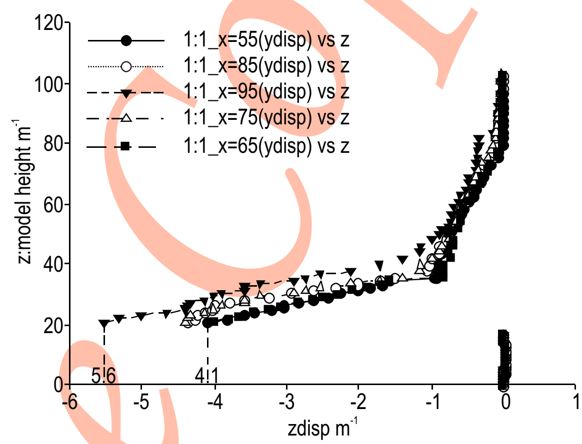


Fig. 6 : Stratum and coal vertical displacement on observation lines in section A (y=100 m) when ratio was 1:1

The roof and floor of No. A4 coal seam were moderately stable rock. The roof was mainly comprised offine sandstone, and the floor was mainly comprised of silt stone, their composition was quartz, feldspar, and calcium cementation, where there was a strong convergence between the layers. There were some physical and mechanical tests of rocks which form the No. A4 coal seam roof and floor have been carried out, with geological prospecting. The test results indicate that the uniaxial compressive strength was72.6Mpa of No.A4 coal seam roof rock, and the uniaxial compressive strength was71.0Mpa of No.A4 caol seam floor rock, in the natural state.

With regards to the working face, along the strike direction of the mine, the whole No.A4 coal seam was divided into east and west wing mining area, in relation to the main shaft. Then, the working face along the strike direction was 750 m, and its width along inclination was 45 m. According to the coal seam occurrence conditions and production technique, the fully mechanized top coal caving was adopted in the horizontal slice working face, with a mining height of 2.5 m. The profile of the working face is shown in Fig.1.

Description of the numerical model :

Geometry size of the model : To find a universal principle of surrounding rocks destruction in fully mechanized top coal caving, a three-layer model was built, where the layers were roof, No. A4 coal seam, and floor, as shown in Fig. 2.

In the model, the length, width and height of the model were 195, 200 and 105 m. The x-direction, y-direction and z-direction was the North-South direction of stratum, the East-West direction of stratum and vertical direction. It should be noted that the range of z-direction was elevation +710m to +815m, and the ground elevation was +1050 m. The meshes of the model are shown in Fig.3.

According to the geological conditions of the model, the boundary conditions and mechanical parameters of the model are follows:

1. The top of the model was stress boundary, the stress σ_z was calculated by formula (1) as follows (Tan, 2007)

$$\sigma_z = \gamma H \quad (1)$$

Table 2 : Properties of rock and coal

Parameter	Density (kg m^{-3})	Bulk modulus (GPa)	Shear modulus (GPa)	Cohesion (Mpa)	Tensile strength (Mpa)	Friction (°)	Poisson ratio
Fine sandstone	2873.00	2.2	1.515	3.20	1.29	42.00	0.22
No.A4 coal seam	1350.00	2.07	0.85	1.35	0.15	26.00	0.32
Siltstone	2563.00	4.1	1.677	3.50	1.53	39.00	0.32

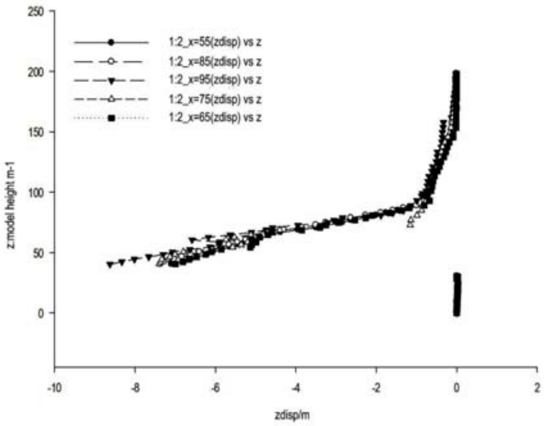


Fig. 7 : Stratum and coal vertical displacement on observation lines in section A (y=100) when ratio was 1:2

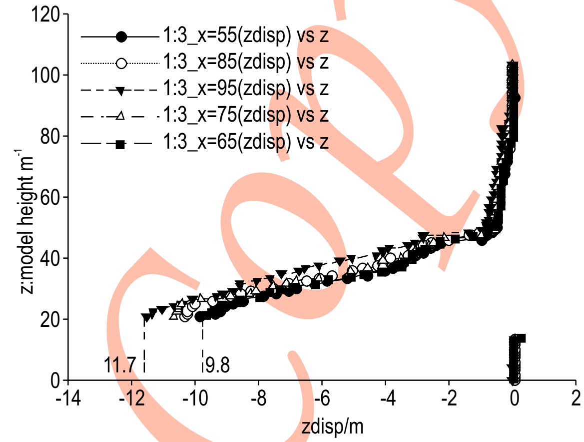


Fig. 8 : Stratum and coal vertical displacement on observation lines in section A (y=100) when ratio was 1:3

where, γ is the body force of overlying rock, the value of 25 kN m^{-3}; *H* is the depth of the top to ground, the value of 235 m; σ_z is the equivalent load to model from the overlying rock.

2. On the position of x=0, x=195, and y=0, y=200 imposed horizontal restraint, these boundary displacements were zero. The horizontal restraint caused by gravity stress σ_x and σ_y was calculated by formula (2)

$$\sigma_x = \sigma_y = \lambda\sigma_z \quad (2)$$

where, the σ_x is the horizontal restraint stress on the x-direction, and σ_y is the horizontal restraint stress on the y-direction, the λ is a coefficient of horizontal stress, at the value of 1.2. According to the formula (2), the equivalent load σ_z is 5.875 Mpa, the horizontal stress σ_x and σ_y are 7.05 Mpa.

With a fixed boundary of z=0, the vertical displacement and horizontal displacement of the bottom boundary was zero.

According to the results of rock mechanics tests, the rock mass was damaged when load reache ultimate strength, and the residual strength of rock mass was decreased gradually with the development of deformation, after the process of plastic flow. The Mohr-Coulomb model was also used in the present model (Tan 2007; Gao 1999; Zhou and Yang 2005), and the rock mass properties were mainly determined according to the experiments from the Xigou Coal Mine as shown in Table 2.

In the modeling scheme of the present study, destruction patterns of surrounding rock were analyzed in a fully mechanized top coal caving when the mining and caving was 1:1,1:2 and 1:3, respectively, according to the following steps.

Ground stress is the stress caused by gravity and tectonic movement. It can be divided into four kinds on the basis of origin; gravity stress, tectonic stress, residual stress and aberrance stress (Yuan *et al.,* 2007). Initial ground stress was the basis of engineering simulation, which affects the accuracy and reliability of the results directly. There were many factors influencing ground stress distribution, but in order to simulate the distribution characteristics of initial ground stress in the regional engineering, gravity stress and tectonic stress (Hou *et al.,* 2007). At present, there were three methods used to solve the initial ground stress, which are as follows, plastic method, elastic-plastic method, elastic-plastic method. In the present study, rapid stress boundary method was used to solve the initial ground stress (Li *et al.,* 2002).

In the simulation of excavation, the mining height was 3 m, the space of fully mechanized top coal caving was $z \in (10, 16)$, $z \in (10, 19)$ and $z \in (10, 22)$ when the mining and caving ratio were 1:1,1:2 and 1:3. The working face began at y=50 m, and the balance of the ground stress was calculated after extracted per 5 m, until the working face was extracted 100 m.

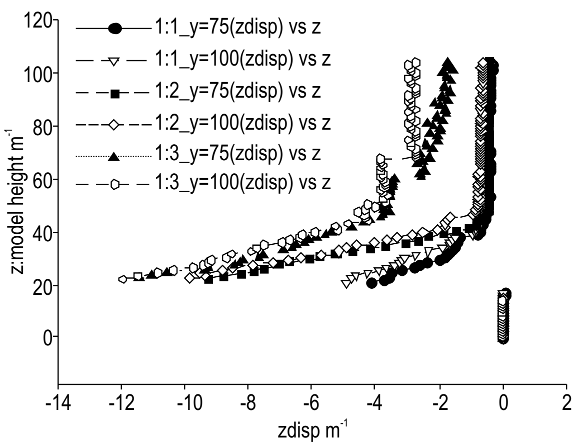


Fig. 9 : Stratum and coal vertical displacement on observation lines in section B (x=55 m)

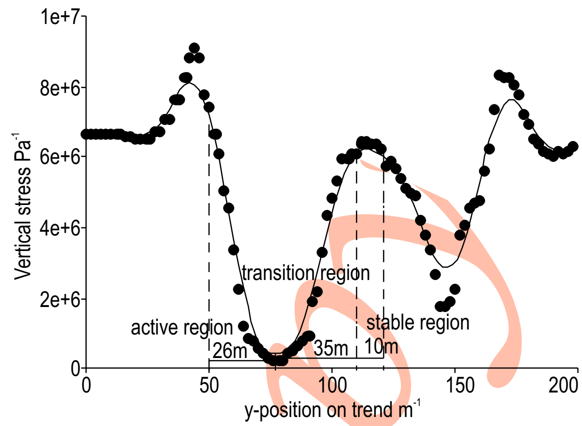


Fig. 10 : Vertical stress distribution on section z=60 m along with trend direction, (ratio was 1:1)

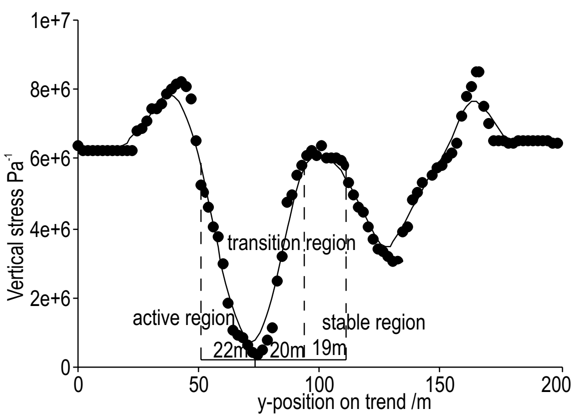


Fig. 11 : Vertical stress distribution on section z=60 m along with trend direction, (ratio was 1:2)

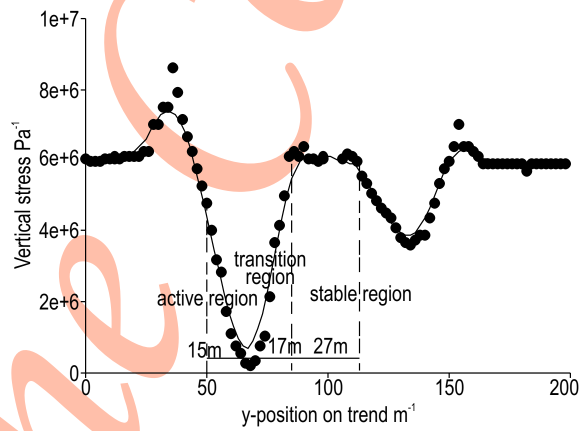


Fig. 12 : Vertical stress distribution on section z=60 m along with trend direction, (ratio was 1:3)

According to data observation and analysis, the tendency established a section A (y=100 m) in the model, and set 5 displacement observation lines in section A; they were x=45m,x=55m, x=65m,x=75m and x=85m (Fig.4). According to the trend, a section was established (x=55 m) in the model, and two displacement observation lines were set in section B, which were y=75m, y=100m (Fig. 5). Using Sigmaplot 12.5 program displacement data based on observation lines was analyzed.

In roof strata, the tendency of extrusion structure and counter tendency structure are formed. Different kinds of structure exist in different areas along the tendency. The homo-shell structure was formed around the coalface.

The envelope shape of homo-shell structure section along the tendency and strike can be described as nonlinear quadratic function which contains the parameter coal seam dip angle, mining height, face length and roof rock properties ect. (Wu *et al.,* 2010; He *et al.,* 2008). After coal seam caved, the main failure mode of the overlay rock was tensile-shear failure, and asymmetric phenomenon will lead the rock-fall periodic to the difference (Wu *et al.,* 2010).

On incline direction, when the working face were extracted 100 m, the vertical displacement characteristic of stratum and coal could be analyzed by data from observation lines in section A (Fig.6, Fig.7 and Fig.8).

The principles of ground surface deformation caused by mining of deeply inclined coal seam with horizontal ground surface deformation caused by mining of coal seam movement were distinct from one another (Zhang, 2013). When the dip angle of coal seam was 45 degrees, the stratum and coal vertical displacement of right side (x=95 m) at working face was greater

Table 3 : The range of three areas with different mining ratio

Mining ratio	Stable region	Transition region	Active region
1:1	10 m	35 m	26 m
1:2	19 m	20 m	22 m
1:3	27 m	17 m	15 m

than left side (x=55 m). With increase of mining and caving ratio, this asymmetric phenomenon of vertical displacement became more obvious. On the same height, vertical displacement differences between both sides of the working face were 1.4 m, 1.7 m and 1.9 m, when the mining and caving ratio was 1:1 (Fig.6), 1:2 (Fig.7), 1:3 (Fig.8). Generally, the vertical displacement of overlay rock and coal became greater with an increase of dip angle and distance on the inclined direction.

When the working face was extracted 100 m, mining and caving was 1:1, 1:2 and 1:3. The vertical displacement of overlay rock and coal on observation lines in section B (x=55 m) is shown in Fig.9. According to same ratio and height of the model, the vertical displacement difference between two observation lines was small, between L6 and L7. It deduce that the rock's deformation was continuous before fracture, even if broken, the displacement difference would be small because of the rock's hulking coefficient and vertical stress (Li *et al.,* 2008).

Generally, mined out can be divided into three zones according to the distribution of vertical stress These are the active region, the transition region and the stable region (Chen *et al.,* 2014). In this case, the vertical stress distribution on section z=60m, as shown in Fig. 10, Fig. 11, and Fig. 12, along with the trend direction. And the range of the three regions with different mining ratio is shown in Table 3.

In conclusion, the results showed that the migration of overlay rock in goaf had following characteristics: On the inclined direction, the vertical displacement of overlay rock and coal became greater with an increase of dip angle and distance, and with an increase of mining and caving ratio, the asymmetric phenomenon of vertical displacement became more obvious. According to the direction of the trend, the active region and the transition region in goaf became smaller along with an increase of mining and caving ratio. On the contrary, the stable region area became greater.

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References

Chen, S.L., H.J. Wang and Y.C. Li: The scope of fracture zone measure and high drill gas drainage technology research. *J. Chem. Pharmac. Res.,* **6**, 450-457 (2014).

Gao, Y.F.: Rock triaxial pressure text and rock damage mechanics. Seismological Press (1999).

He, M.C., X.Y. Wang, W.T. Liu and B.S. Yang: Numerical simulation on asymmetric deformation of deep soft rock roadway in Kongzhuang Coal Mine. *Chin. J. Rock Mech. Engee.,* **4**, 673-678 (2008).

Honkanadavar, N.P., N. Kumar and M. Ratnam: Modeling the behaviour of alluvial and blasted quarried rockfill materials. *Geotech. Geol. Engee.,* **32**, 1001-1015 (2014).

Hou, M.X. and X.R. Ge: Study on fitting analysis of initial stress field in rock masses. *Rock and Soil Mechanics,* **28**, 1626-1630(2007).

Jiang, F.X., L.H. Kong and C.G. Liu: Gas emission laws of fully-mechanized sublevel caving mining in extra-thick coal seam. *J. China Coal Soc.,* **36**, 407-411 (2011).

Li, R.F., Y.P Liang and G.Q. Cheng: Study on law of strike horizon displacement about Overburden of Goaf. *Saf. Coal Mines,* **4**, 8-11 (2008).

Li, Z.K., R. Dai and Y.M. Jiang: Improvement of the generation of the initial stress field by using FLAC3D and application in a huge underground cavern group. *Chin. J. Rock Mech. Engee.,* **21**, 2387-2392 (2002).

Meng, X.R., H.P. Wang, C.H. Liu and Y. Zhang: Selection principle and development status of thick seam mining methods in China. *Coal Sci. Technol.,* **37**, 39-44 (2009).

Ren, W.X., D.M. Wang, F.B. Zhou and X.F. Bie: Spontaneous combustion cause and preventing technology at high caved area in soft and extra-thick seam. *J. China Coal Soc.,* **35**, 24-28 (2007).

Tan, Y.L.: Mining pressure and strata control. Peking: China Coal Industry Publishing House, **2**,121-133(2007).

Wang, G.P.: Study on impact and restoration of ecological environment of mining subsidence in Chongqing region. *J. Chongqing University,* **10**, 3-8 (2005).

Wang, J.A., Z.G. Gao, L. Wang and T. Liu: Study on mine pressure behavior under different mining-caving ratio with fully-mechanized mining. *Metal Mine,* **10**, 8-11(2013).

Wang, J.C. and S.H. Zhong: The present status and the key issues to be resolved of thick seam mining technique in China. *Science Paper Online*, **11**, 829-834 (2008).

Wang, J.C., L.K. Wei, J.W. Zhang and Z.L. Li. 3-D numerical simulation on the top-coal movement law under caving mining technique. *J. China Coal Soc.,* **38**, 1905-1911(2013a).

Wang, J.C.: Fully mechanized long wall top coal caving technology in China and discussion on issues of further development. *Coal Sci. Technol.,* **33**, 14-17 (2005).

Wang, W.F., X. Chen, G.P. Luo and L.H. Li: Modeling the contribution of abiotic exchange to CO2 flux in alkaline soils of arid areas. *J. Arid Land,* **6**, 27-36 (2014).

Wen, Z., G. Qu, J. Wen, Y. Shi and C. Jia: Deformation failure characteristics of coal body and mining induced stress evolution law. *The Scientific World J.,* **10**, 1-8 (2014).

Wu, P.Y., P.S. Xie and S.G. Ren: Analysis of asymmetric structure around coal face of steeply dipping seam mining. *J. China Coal Soc.,* **2**, 182-184 (2010).

Wu, Y.P., P.S. Xie and S.G. Ren: Analysis of asymmetric structure around coal face of steeply dipping seam mining. *J. China Coal Soc.,* **35**,

182-184 (2010).
X.M. Fan: Research on improving recovery rate of fully mechanized caving mining in flat thick coal seam. *J. Taiyuan Univ. Tech.,* **41**, 756-758 (2010).
Xu, Y.Q.: Mining science. XuZhou: China University of Mining and Technology Press, (2009).
Yasitli, N.E. and B. Unver: 3D numerical modeling of long wall mining with top-coal caving. *Inter. J. Rock Mecha. Min. Sci.,* **42**, 219-235 (2005).
Yuan, F.B., J. Liu, P.J. Li, L.P. Qiao and P. Li: Back analysis and multiple-factor influencing mechanism of high geo stress field for river valley region of Laxiwa Hydropower Engineering. *Rock and Soil Mechanics,* **28**, 836-842 (2007).
Zhang, L.L.: A certain mining area of Chongqing the inclined coal-seam mined causes surface movement deformation mechanism and geological environment problems. *Chengdu Univ. Technol.,* **6**, 1-5 (2013).
Zhou, W.Y. and Q. Yang: Numerical computational methods for rock mechanies. China Electric Power Press (2005).