Journal of Applied Sciences

ISSN 1812-5654

Journal of Applied Sciences 13 (13): 2538-2543, 2013
ISSN 1812-5654 / DOI: 10.3923/jas.2013.2538.2543

A Computer Aided Design and Simulation System for Upward Cross-seam Boreholes

[1,3]Hou Shao-Jie, [1]Zhang Yu-Wei and [2]Cheng Yuan-Ping
[1]Computer Center, Hebei University of Economics and Trade, Shijiazhuang, Hebei, 050061, China
[2]Key Laboratory of Gas and Fire Control for Coal Mines,
Ministry of Education, University of Mining and Technology, Xuzhou, Jiangsu, 221116, China
[3]Post-doctoral Scientific Research Workstation,
Shanxi Coking Coal Group Co., Ltd, Taiyuan, Shanxi, 030024, China

Abstract: In order to prevent gas hazards, thousands of upward cross-seam boreholes for gas pre-drainage are widely used in underground coal mines. Their construction quality directly determines whether coal gas accidents happen and touches miners' lives closely. However, the quality is difficult to be guaranteed, because of the hostile underground environment, complicated spatial calculation, sightless strata reserves and little digitalized supporting. Based on the vector algebra theory, a novel algorithm is proposed which abstracts boreholes as a set of vectors and calculates their parameters step by step. The algorithm consists of three parts that are borehole path calculation, the computation of boreholes group distribution and additional boreholes designing. Then an algorithm-based design and simulation software system is developed which follows a strict logical flow and implements five functions, namely importing basic data, the 1st designing, storing construction data, rendering virtual scene and appending additional boreholes. At last, through application case in Qinan coal mine, the system is proved to be objective, effective and helpful to simplify design effort and improve visualization.

Key words: CAE, digital mine, regional gas control, cross-seam borehole

INTRODUCTION

With the coal exploitation extending to depth rapidly in China, high geo-stress, high gas, high inhomogeneous, low permeability and low coal mass strength, namely the phenomenon of "three high and two low", makes the problem of coal and gas outburst becoming more and more outstanding. To avoid touching outburst coal seam closely, the gas pre-drainage technology by upward cross-seam boreholes has been widely researched and utilized from a variety of aspects (Cheng *et al*., 2009), such as grid drilling to the protected coal layer, intensively drilling to the single coal seam, drilling in the rock cross-cut coal uncovering, etc. (SAWS, 2009).

However, a huge number of cross-seam boreholes have to be designed and constructed manually. In the hostile underground environment, complicated spatial relationship and sightless strata reserves facilitate various mistakes and the construction quality is difficult to be guaranteed. The inhomogeneous coverage and numerous blank zones give rise to gas power phenomenon easily, even gas outburst accidents. Meanwhile, the high quality construction of cross-seam boreholes is imposable to be accomplished in one time and the miners often have to append a mass of additional boreholes which make the manual designing work more and more cumbersome and incapable.

Recent years, information and automation techniques were integrated with coal industry (Scoble, 1995; Kaufmann and Martin, 2008; Wu *et al*., 2012; Zhu *et al*., 2006, 2012) and a lot of software systems have sprung up (Zhang *et al*., 2010), such as Micromine (Samal and Sarangi, 2001), Minesight32D (Cai *et al*., 2001), Surpac, DataMine, AMSKAN, PENDM (Xiong *et al*., 2012), etc. In them, coal reserves calculating, production planning, material and financial management was well supported (Duskey, 2006; Trenczek and Wasilewski, 2008). However, all of them lacked the ability of computer aided design for upward cross-seam boreholes of gas extraction.

Therefore, it is necessary and urgent to build a comprehensive and easy-to-use software system which can design cross-seam boreholes rationally, manage relevant data normatively and append additional boreholes simply. In this study, adopting vector algebra and information technology, the expected system is

Corresponding Author: Hou Shao-Jie, Computer Center, Hebei University of Economics and Trade, Shijiazhuang ,050061, China
Tel: 8618233103202

developed in VS.Net 2010 and relevant parameters are stored in SQL Server 2008. To improve the perspective ability of numerous boreholes, XNA technology is used to render the virtual scene of constructed boreholes.

COMPUTATIONAL ALGORITHM

Calculation of borehole path: According to regional coal gas prevention techniques (SAWS, 2009), the upward cross-seam boreholes are opened at the drill field on side of floor roadway which is located about 20-30 m under coal seam. Under ideal condition, boreholes paths traverse coal seam at least 0.5 m and their bottoms form a regular grid distribution. But in practice, the effect is difficult to reach and boreholes designing, constructing and management are a repeated process of improvement.

In geographic space, the coal seam and drill field can be respectively described as a planate cube and a small cube; the upward cross-seam borehole is a slender cylinder determined by three parts that are digging position, path direction and cross-section size, as shown in Fig. 1.

In Fig.1, each borehole path can be abstracted to a vector, remembered as $\vec{b}$ which start point lies in the top or front plane of the drill field and end point lies in the parallel plane of the coal seam roof:

$$\vec{b} = \overrightarrow{ST} = \{x_1 - x_0, y_1 - y_0, z_1 - z_0\} \quad (1)$$

where, S is the start point (x_0,y_0,z_0), T is the end point (x_1,y_1,z_1).

Serving for construction, the design parameters of each borehole include seven items: Name (n), offset to drill field floor (o_1/m); offset to drill field left wall (o_2/m); azimuth angle (α/degree, negative when digging left, positive when digging right and 0 when digging front); inclination angle (β/degree); path length (l/m); borehole diameter (φ/mm), described as following:

$$d = (n, O_1, O_2, \alpha, \beta, l, \varphi) \quad (2)$$

In view of the control range, S and T points described in (1) can be determined and parameters in (2) is our computation goal. Then the design algorithm is a calculation procedure from (1) to (2).

Based on the analysis shown in Fig.2, the calculation procedure consists of five steps:

Step 1: The length of borehole path is the module of vector $\vec{b}$:

$$l = |\vec{b}| = \sqrt{(x_1 - x_0)^2 + (y_1 - y_0)^2 + (z_1 - z_0)^2} \quad (3)$$

Step 2: Calculating two auxiliary vectors named as $\vec{m}$ and $\vec{n}$. They start at point S; $\vec{m}$ is the unit vector along Y axis; $\vec{n}$ is the projection vector of $\vec{b}$ in plane XOY, described as following:

$$\begin{cases} \vec{m} = \{0,1,0\} \\ \vec{n} = \{x_1 - x_0, y_1 - y_0, -z_0\} \end{cases} \quad (4)$$

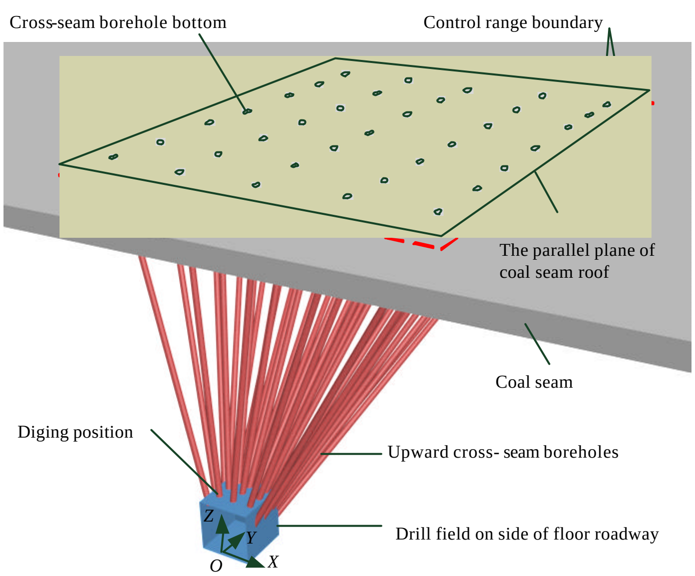

Fig. 1: Schematic diagram of gas pre-drainage technology by upward cross-seam boreholes

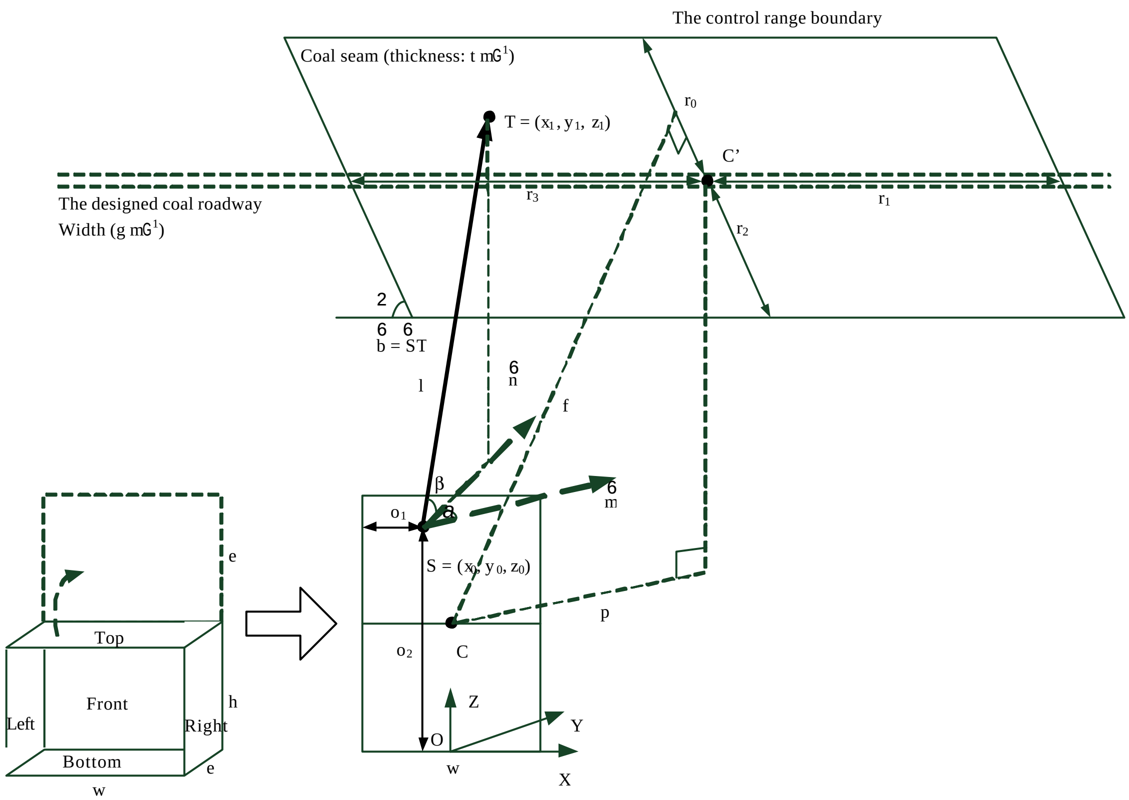

Fig. 2: Spatial relations between the control range, drill field and boreholes

Step 3: α and β describe the intersection angles between $\vec{m}$ and $\vec{n}$, $\vec{b}$ and $\vec{n}$. They can be easily gained by the following expressions:

$$\begin{cases} \cos\alpha = \dfrac{\vec{m}\bullet\vec{n}}{|m||n|} \\ \cos\beta = \dfrac{\vec{b'}\bullet\vec{n}}{|b'||n|} \end{cases} \tag{5}$$

Step 4: Borehole diameter φ is determined by boring crown, usually 90 or 100 mm

Step 5: The rest parameters n, o_1, o_2 are used to arrange the grid distribution of boreholes' bottoms will be discussed subsequently

Boreholes group distribution computation: According to the control range, there are a group of boreholes to be designed and constructed in each drill field. In order to homogenously pre-extract coal gas, the positions of those boreholes' bottoms should lie in grid and cover the whole control range. For construction convenience, the digging positions are also designed in a miniature mesh corresponding to the bottom grid.

As shown in Fig. 2, the spatial coordinate system is established and C is the top-front line midpoint. Remembering the drill field size as $w\times e\times h/m^3$, then C = (0,e,h). C' is the center of control range and its distances from four boundaries are recorded as (r_0, r_1, r_2, r_3). Remembering the coal seam inclination angle as θ/m, the horizontal distance as p/m, the normal distance as f/m, then C' coordinate is (0,p+e,f/cosθ-ptanθ).

Remembering the extraction radius as r/m, the designed coal roadway width as g/m, the rs*cs grid layout can be obtained, where rs is row count and cs is column count:

$$\begin{cases} rs = \lceil 0.7(r0+r2)/r \rceil \\ cs = \lceil 0.7(r1+r3)/r \rceil \end{cases} \tag{6}$$

Based on above calculation, the start (S) and end point (T) of each borehole vector in the group can be acquired and then be described as the vector $\vec{b}$ which is the basis of borehole path calculation. Meanwhile, the rest parameters, namely o_1 and o_2 can be gained easily. Referring grid distribution, we set n as the string D[row index][column index], such as D00, D01, D02, ...

Design of additional boreholes: Under ideal condition, bottoms of boreholes in the same group form a regular mesh layout. But in practice, the construction is often far away from its design because of poor perspective ability. Then engineers have to eliminate blank zones after the 1st construction through repeatedly appending additional boreholes. For this, we develop 3D virtual scene of constructed boreholes in our software system, in which engineers can visually identify blank zones and supply additional boreholes. Then above algorithm can run again to gain the design parameters of additional boreholes.

SYSTEM DEVELOPMENT

Base on above algorithm, a computer aided design system was developed in VS.Net 2010 and SQL Server 2008. Its logical flow contained five steps:

Step 1: Basic data importing
Step 2: The 1st designing which results in the original borehole parameters
Step 3: Storing boreholes' design and construction data
Step 4: Rendering the virtual scene of constructed boreholes
Step 5: Identifying blank zones and appending additional boreholes. In particular, the 5th step is a loop which should run repeatedly until eliminate blank zones completely, as shown in Fig. 3

The software provides two windows for users to input their information, including basic data and the start-end location of additional boreholes. The designing function runs automatically in background and generates a set of borehole parameters. Droved from those data, XNA technology is used to render 3 day scene of constructed boreholes, including coal seam, drill field and boreholes, in which user can visually identify blank zones and propose expected additional boreholes.

APPLICATION CASE

The Qinan colliery is located in Suzhou country, Anhui province, China, where the No.7 coal seam is the riskiest outburst seam, with an average thickness of 2.64 m, average inclination of 10 degrees. It has been determined that the gas pressure is 3.5Mpa at -550 m level and the gas content is between 12.29 and 15.38 m^3 t^{-1}. Since 1997 there have been total 6 times of gas power phenomenon happened with 171 tons of outburst coal rocks and 32, 160 m^3 of gas.

The No. 716 mining face, with size of 983×180 m^2, lies at the 3rd segment on right flank of the No.81 mining area which utilizes upward cross-seam boreholes to pre-extract coal gas and eliminate outburst hazard in the strip area near designed coal roadway. We take the designed coal roadway as the midline of stripe control range, where 39 drill fields and 2134 boreholes were constructed.

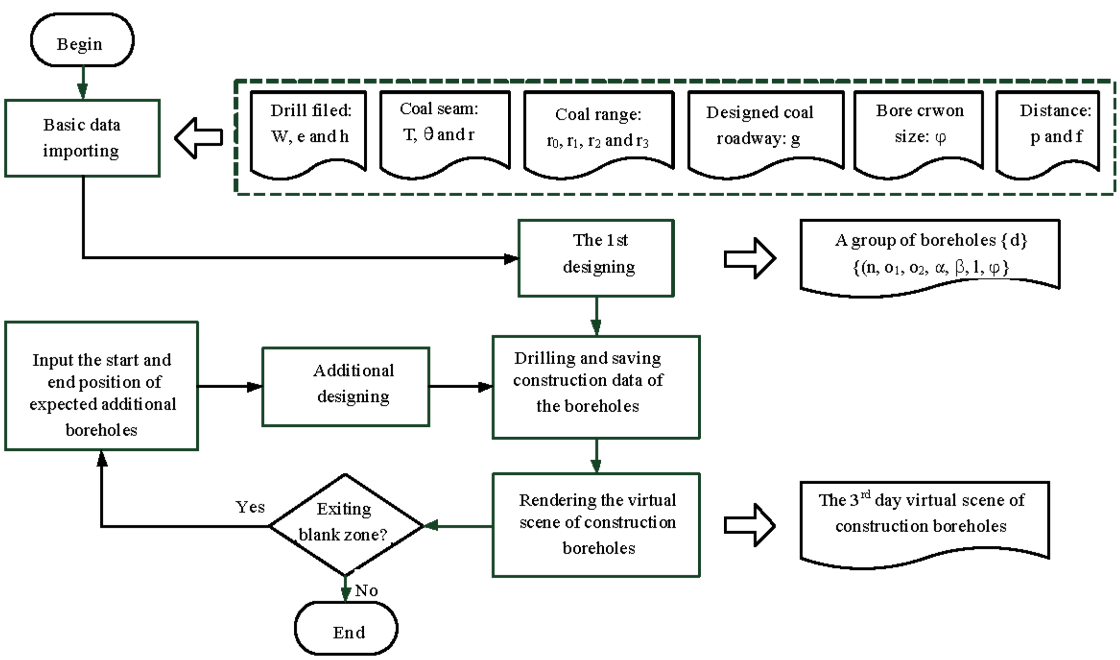

Fig. 3: Logical flow of the computer aided design and simulation system

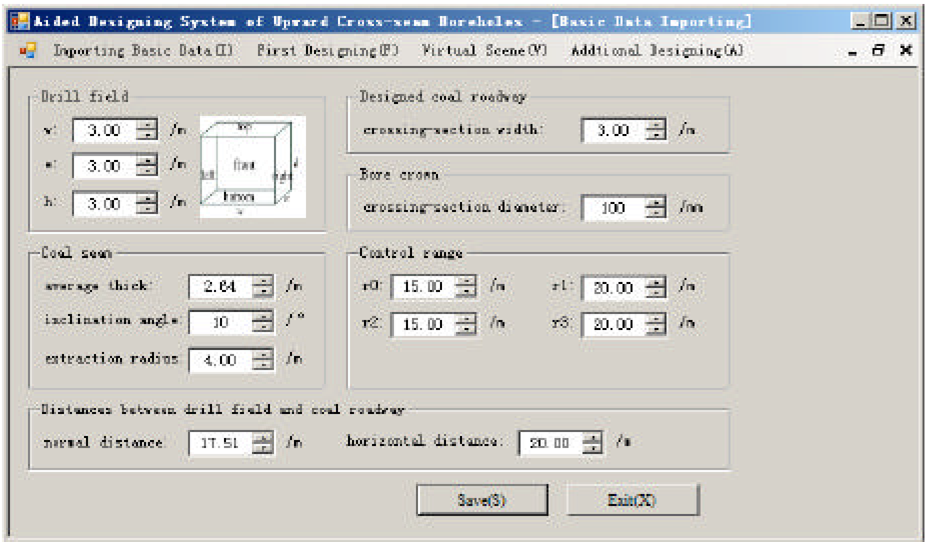

Fig. 4: Basic data importing interface

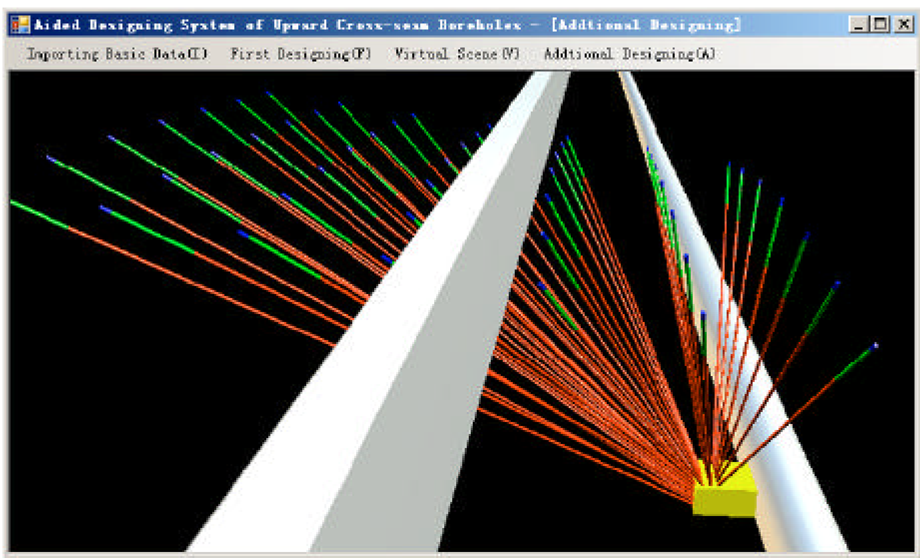

Fig. 5: Virtual scene droved by boreholes construction data

The No. 2 drill field was selected to test the developed software. First of all, the basic data were entered, including parameters of drill field, coal seam, control range, designed coal roadway, bore crown size, distance between the No. 2 drill field and the designed coal roadway, as shown in Fig. 4.

Secondly, by clicking menu item "First Designing", the 1st designing was completed and borehole's designing parameters were shown in a table automatically, containing seven columns: Name (n), offset1 (o_1), offset2 (o_2), azimuth angle (α), inclination angle (β), length (l) and diameter (φ).

After construction, the corresponding drilling data must be inputted into the system.

Subsequently, by clicking menu item "Virtual Scene" the virtual scene was rendered. The scene contained the floor rock roadway, the No. 2 drill field, the designed coal roadway and all constructed cross-seam boreholes which was synchronous to boreholes data and would fresh automatically when appending additional boreholes data, as shown in Fig. 5.

At last, we identified blank zones in the virtual scene and supplied expected additional boreholes position into system until all blank zones were eliminated.

CONCLUSION

In underground collieries, due to the hostile environment, invisibility, designing manually and poor management ability, the widely used upward cross-seam boreholes specially trended to generate numerous blank zones which gave rise to gas power phenomenon and even outburst accidents easily.

To simplify the design effort of upward cross-seam boreholes, we proposed a novel, integrated algorithm and developed its supported software system. To see the underground construction scene visually, virtual reality technique was integrated into the software system.

We abstracted the upward cross-seam boreholes to vectors and calculated them through a series spatial calculation, including borehole path calculation, boreholes group distribution computation and the design of additional boreholes.

By synthesizing three correlated parts of the proposed algorithm into a standardized logical flow, a computer aided design and simulation software system was developed. In it we implemented four functions, including basic data importing, the 1st designing, data management, virtual scene rendering, blank zones identification and design of additional boreholes. In particular, its flow path was a loop and its end meant that blank zones had vanished.

By test in Qinan coal mine, the software system was proved to be fully considered user experience, easy-to-use, effective and objective. Meanwhile, its virtual scene rendering improved visualization of the underground working significantly.

ACKNOWLEDGMENTS

The financial support by National Natural Sciences Foundation of China (Grant No. 51104052), College Scientific Research Projects in Hebei Province (Grant No. Y2012038) and Key Laboratory of Gas and Fire Control for Coal Mines (China University of Mining and Technology) of Ministry of Education (GFCKF201108) are deeply appreciated.

REFERENCES

Cai, W.L., X. Gao and J.G. Ren, 2001. Computerized mine model in gand planning at jiangxi copper company limited mines. Comput. Appl. Minerals Ind., 29: 179-182.

Cheng, Y.P., J.H. Fu and Q.X. Yu, 2009. Development of gas extraction technology in coal mines of China. J. Mining Safety Eng., 26: 127-139.

Duskey, M.R., 2006. Digital control updates let old shovels give new models a run for their money. Eng. Mining J., 207: 66-69.

Kaufmann, O. and T. Martin, 2008. 3D geological modelling from boreholes, cross-sections and geological maps, application over former natural gas storages in coal mines. Comput. Geosci., 34: 278-290.

Samal, A.R. and P. Sarangi, 2001. Micromine in the world of mineral exploration and mining. Proceedings of the Indian Conference on Computer Applications in Mineral Industry, New Delhi, March 18, 2001, pp: 123-134.

Scoble, M., 1995. Canadian mining automation evolution: the digital mine enroute to mine wide automation. CIM Bull., 88: 30-37.

SAWS, 2009. Coal and gas outburst prevention regulations. State Administration of Work Safety

Trenczek, S. and S. Wasilewski, 2008. Innovativeness of power supply systems, computer technologies and automation involved in technological processes of coal mining. Gaspodarka Surowcami Mineralnymi-Mineral Resources Manage., 24: 89-102.

Wu, L.X., Y.J. Wang, E.J. Ding, W.X. Zhu, R.X. Zhang, S. Zhang and Z. Wang, 2012. Thirdly study on digital mine: Serve for mine safety and intellimine with support from IoT. J. China Coal Soc., 37: 357-365.

Xiong, S.M., L.G. Wang, J.X. Huang and J.H. Chen, 2012. Parametric data model for underground mine 3D visual production management and control system. J. Central South Univ. (Sci. Technol.,), 43: 273-277.

Zhang, X.L., C.L. Wu and Z.P. Weng, 2010. Research and application of the digital mine software Quanty mine. Earth Sci.-J. China Univ. Geosci., 35: 302-310.

Zhu, L.F., Z. He, X. Pan and X.C. Wu, 2006. An approach to computer modeling of geological faults in 3d and an application. J. China Univ. of Mining Tech. (English Edn.,), 16: 461-465.

Zhu, L., C. Zhang, M. Li, X. Pan and J. Sun, 2012. Building 3D solid models of sedimentary stratigraphic systems from borehole data: An automatic method and case studies. Eng. Geol., 127: 1-13.