Prediction Model of Water Flooding in Mine Sites using 3-D Simulation Technology

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***Abstract* — In this paper, a new data structure and method are presented for reconstruction of underground mine water invasion environment in a 3-Dimensional (3D) by simulation and 3D visualization. Before predicting mine water invasion, octree segment simulation was applied to tune the simulation model and sector indicator statistical analysis was made through the searching eclipse of spatial octant. An effective spatial topology tree was then established in accordance with the time sequence for dynamic simulation of water invasion. The reconstructed mine tunnel model in which water invasion was expected proved to be basically in agreement with realistic water invasion environment, while the 3D segmented octree model proved fully capable of spatial state simulation of water invasion. Thus, the application of mine water invasion model established with spatial searching octant can well be used for the simulation of water invasion trajectory, and the acquired indicator for water invasion confirms the realistic situation.**

Keywords - three-dimensional visualization; octree; water bursting forecast; space octant

I. INTRODUCTION

The abruptness and reoccurrence of mine water inrush plus the complexity of the mining production system make the predictions of the affecting area, the process and severity of water inrush difficult within a short period of time. Productive control of mine water inrush lies in effective simulation and prediction of the flow path of inrushing water [1-2]. In light of modern technology development in recent years, 3D visualization has been widely applied in the mining engineering, the environmental engineering, the civil engineering and urban construction [3-4]. The constant development of 3D visualization offers strong technique for the simulation of mine water inrush. Based on the characteristics of the mine water inrush accident, this paper provides a representation of mine water inrush environment using 3D visualization techniques. The octant section searching method was applied for the simulation of spatial information of the current path. A time sequence operation was then conducted upon the acquired information to establish a predication database for the mine water inrush accidents, which lead to efficient simulation of the water inrush process from the perspective of time and space.

II. PRINCIPLE AND HYPOTHESIS

The purpose of a mine water inrush prediction model is to predict the affecting area and status within the roadway that is subject to the inrushing water by simulating and calculating the position, time, path and volume of underground mine water inrush, and to decide the severity of inundation of the roadway by taking into consideration of both the overall gravitational potential energy and the connectivity of roadways. Since the flowing of water within the roadway is very complicated, this prediction model is built based upon the following hypotheses:

(1) The current assumes only the potential energy, thus no need to consider the capillarity phenomenon in the narrow roadway;

(2) The surface of the roadway is perfectly smooth that no resistant force should be exerted upon the current;

(3) The volume of crevice and crack within the rock stratum is zero, and as a matter of fact the lost volume of water is zero;

(4) The source of inrushing water is known, and strength of the inrushing water is stable.

III. MODELING PROCEDURES

A. The structure of 3D water inrush environment

In geological engineering, the 3D visualized modeling technique is used to build mathematical models that express the relation between the geological structure and relevant elements as well as the geological characteristics of spatial distribution of the physical and chemical property of the geological structure [5-6]. The main subjects of the 3D water inrush environment involve the underground mining development system and the goaf which includes the drift, the vertical shaft, the inclined shaft, the patio and various chambers. Based on the geologically surveyed development plane graph and the projection graph, the 2D linear data which undergo simulation with specific parameters are transformed into a closed Frenet frame model [7] constituted by a series of triangular facets, as shown in Fig.1.

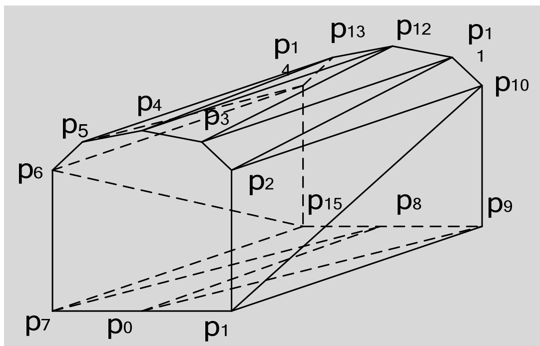

Fig. 1 Closed model of Frenet frame.

In most cases, a 3D inrush water environment model covers all the mining development system, a fact which decides that the Boolean operation [8-10] must be conducted

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upon the different established roadway engineering models to ensure connectivity among all the models. When it comes to the simulation of the inrush water process, the length, width and the inclination of the roadway lay a basis for the prediction of the inrush water and the flow path. Consequently, a correct and well-connected model is required in inrush water environment modeling.

B. The significance of water in rush environment

In essence, the inrush water is a hollowed-out model consisting of a series of concatenated triangular facet. In simulating the inrush water flow path, this hollowed-out model must be divided. The constrain operation is the conducted upon the divided model based on the frame model. At present, the most widely used block modeling technique in practical engineering is the octree modeling method. The main idea of the octree modeling method is described as follow:

Firstly, conduct block constrain operation by specific size upon the internal part of the hollowed-out model; secondly, subdivide the unit block into eight sub-blocks (see Fig.2) from the center. Then repeat this operation upon the sub-blocks till the internal part of the hollowed-out model can be expressed with relatively high accuracy. As to the blocks that lie in the boundary of the model, the subdivision operations upon them are conducted with higher division progression, making sure that the boundary of the block model after the subdivision operation is of infinite linear approximation of the original boundary [11-12] (see Fig.3).

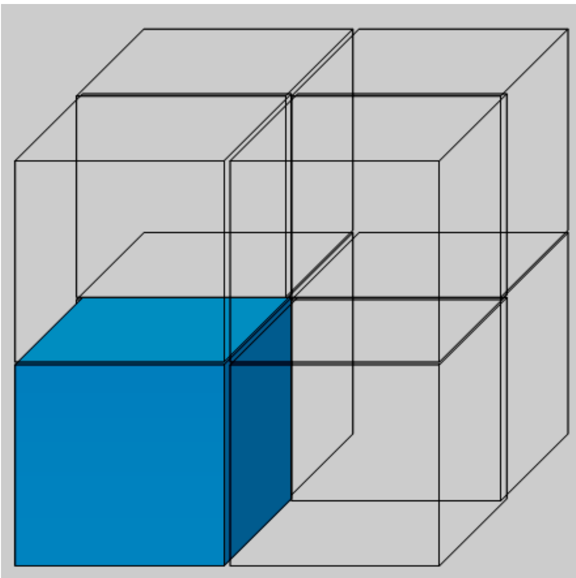


Fig.2 Model of Octree

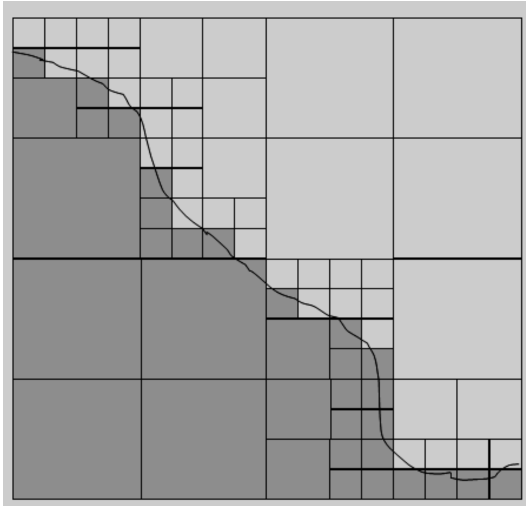


Fig.3 Simulation of boundary.

3D simulation of the inrush water space requires speedy storage of information concerning the spatial coordinates, the current flowing time as well as the topological relation of the sequence of blocks that the water runs through. The particular structure and hierarchy of the octree block model makes the building of a block traverse algorithm easy. The time complexity of this algorithm is lower than that of other algorithms with unstructured data construction [13-15]. As a matter of fact, this structure enables fast mutual access of the spatial block model nodes, and is fully capable of meeting the requirements of water inrush spatial simulation.

C. The deduction of the water inrush process

The deduction of the water inrush process is based upon the spatial block model. The gravitational potential energy property of the current is taken as a reference when it comes to the simulation of inrushing water flowing path. The octant spatial searching technique divides the space into 8 searching areas. A statistical analysis of the block characteristic (see Fig.4) is made via specific ellipse constrain operation.

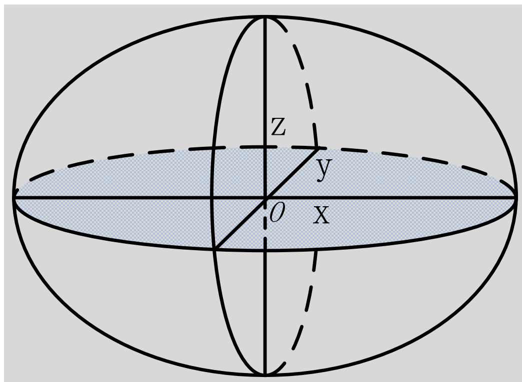


Fig.4 Octant Search Ellipsoid

The process of statistical analysis upon the internal blocks within the space is the simulation process of deduction of the flowing path of current that runs through different blocks. The deduction process goes as below:

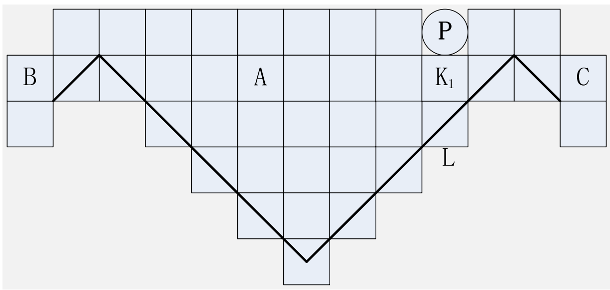
(1) Set the elevation of a certain spatial block Ki as Zi. As shown in Fig.5a, the water inrush source P and spaces A, B and C which are assumes different elevations from P are known, and the boundary line of the roadway is L;

(2) Due to the gravitational potential energy effect, the current leaves P for adjacent blocks with smaller Zi. Build the spatial octant searching ellipsefrom the center of block P, and block K1 shall be found. By parity of reasoning, the current runs through K1 and will eventually reach block K2 that intersects with L as shown in Fig.5b;

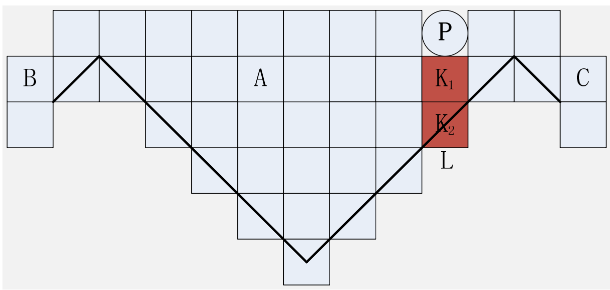
(3) Set K2 as the searching origin, and search again for adjacent blocks whose elevation is smaller than Z2. After an iterative searching process, the current will ultimately run into block K5 whose elevation is of the smallest (see Fig.5c);

(4) Set K5 as the searching origin, if no block with an elevation value smaller than Z5 can be found, search adjacent blocks whose elevation value are equal to or larger than that of Z5, see figure 5d. Branches of the current will run in different directions in the flowing process, so a comparative operation should be conducted among all the object block elevation Zs as determined by the searching ellipse. Blocks with smaller Z boast higher precedence in being filled with water;

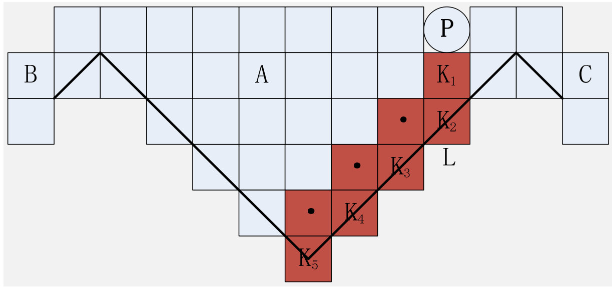
After multiple iterative searching, space A should be filled with water. It is obvious that the current flowing in space B and C obey the same principle as that in space A.



(a)



(b)



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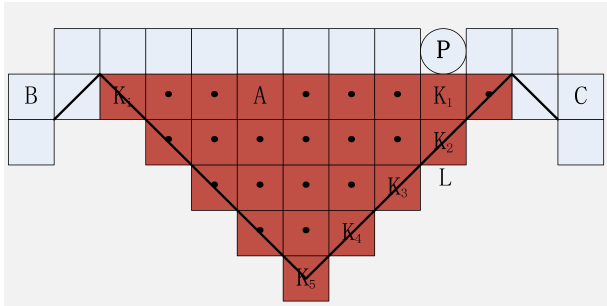

(d)

Fig.5 Path reasoning of water bursting.

D. Topological network of water inrush time

A directed topological network for the block K_i set concerning the time sequence t_i can be built in accordance with the deducted result of the inrush water path. In this network, the vector direction signifies the current flowing path, and the nodes denote the current running position. The topological relation for the inrush water confirms with the flowing rules:

(1) For topological relation in every level of the network, the result of every spatial searching is taken as a goal, based on which directed association is made for the topological relation. The time sequence t_i of block K_i is also recorded;

(2) Blocks which are deemed as the deduction objectives must be adjacent blocks of their direct superior counterparts. Otherwise, blocks which are adjacent to those blocks and their direct superior counterparts should be incorporated into this topological relation, see Fig.5c;

(3) For blocks with ascertained topological relations, no time sequence record is needed to be made again.

IV INSTANCE ANALYSIS OF SIMULATION

A. Data acquisition

The research subject of this paper is part of the roadways of the mining development system. The gathered data (see Fig.6) includes 2D surveyed CAD data concerning the main roadways, branches as well as the liaison roadways. These data are then imported into 3D visualization software to build 3D engineering roadway. The section sizes for the main roadway, the branches and the liaison roadways are respectively.5m×3.2m, 2m×2m and

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2m×2m.

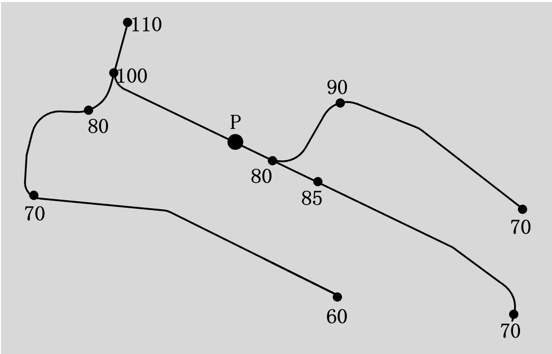
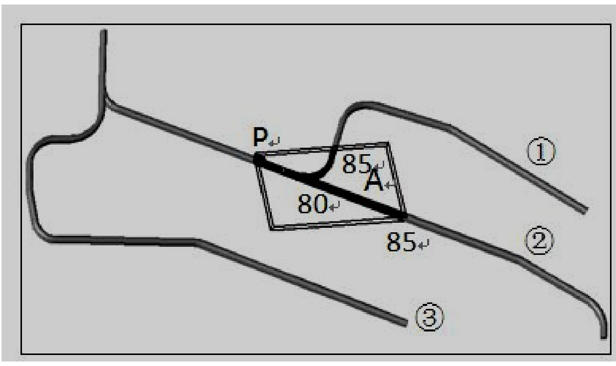


Fig.6 Point figure of Centerline.

B. The simulation of water inrush process

Set the strength of the inrush water source P as 600m3/h. All together 121220 block models in size of 0.4m×0.4m×0.4m are chosen in line with the roadway parameters for roadways where inrush water takes place. The subdivision progression for boundary blocks is 3. An octant searching ellipse with the length of the macro axis, the minor axis and the secondary axis being 1.2m, 0.8m and 0.8m respectively is selected for the inrush water process deduction. The result of deduction is presented in Fig.7.



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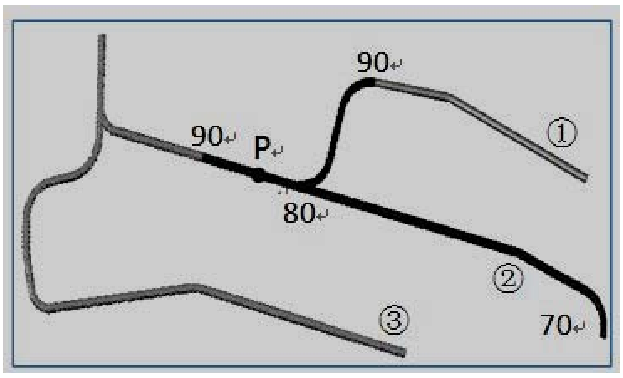

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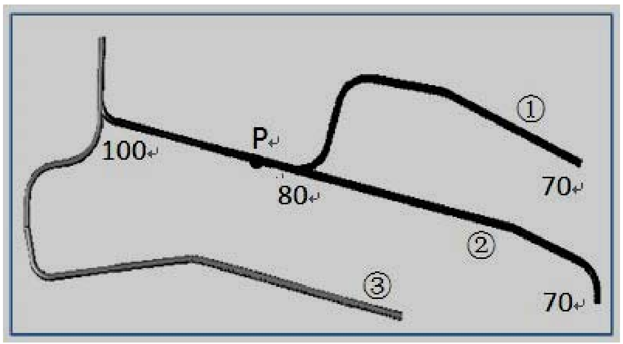
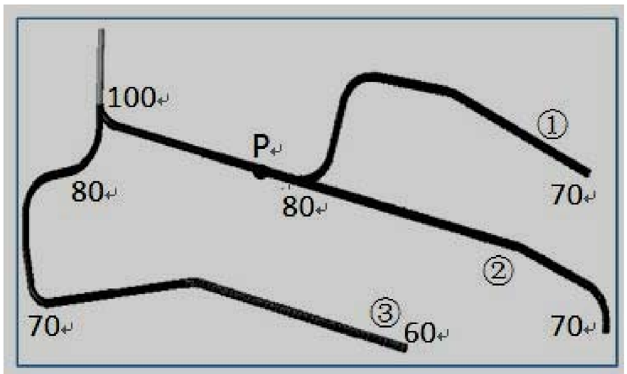


(c)



(d)

Fig.7 Process simulation of water bursting

As is shown in Fig.7, the current leaves the source P and flows along roadway 2 in the eastern direction. The 1st current branch occurs in the roadway whose elevation is 80m. The maximum elevations that the two currents reached in the two roadways are both 85m. As we can see in Fig.7a, the affecting area of inrush water is area A. In Fig.7b, the current continues to flow along roadway 2, and does not digress to roadway 1 until the remaining space of roadway 2 is filled with water. Meanwhile, water in the western part of the roadway 2 starts to rise with the two branches of current ultimately reaching 90m in elevation. Fig.7c shows that the current continues to move in the western direction of roadway 2 when roadway 1 is filled with water. The flow of the current does not stop until the current reach 100m in elevation. In Fig.7d, we see that when roadway 2 is filled with water, the inrushing water gradually fills roadway 3 under the influence of the gravitational potential energy.

C. Result Analysis and Prediction

On the basis of the inrushing water simulation, we can figure out, in line with the inundation time of roadway under conditions of different inrush water radius, the desired parameters of inrush water including the time, volume, position, name and the fullness ratio as presented in Table 1.

TABLE 1 PHYSIC-MECHANICAL PARAMETERS OF ROCKS

Radius r(m)	Time t(h)	Volume v(m^3)	Position			Name	Fullness ratio (%)
			X	Y	Z		
30	0.6	378.4	2716.42	7255.36	84.2	2	10.8
			2746.08	7270.85	89.4	1	6
	6.2	3737.2	2689.45	7294.81	90.3	2	80.1
			2879.25	7169.34	73.3	1	100
60	1.4	822.5	2716.42	7272.86	84.2	2	21.7
			2771.86	7242.19	89.7	1	15.7
	3.8	2300.4	2716.42	7293.66	84.2	2	69.3
			2874.73	7169.34	92.2	1	30.3
	6.7	4014.7	2662.66	7296.77	95.3	2	90.8
			2879.25	7169.34	73.1	1	100
90	4.3	2580	2689.45	7293.66	90.2	2	43.3
			2799.01	7229.09	83.7	1	36.6
	4.9	2910.7	2689.45	7294.81	90.2	2	80.1
			2874.73	7169.34	73.3	1	50.2
	7.1	4253.2	2645.65	7312.54	100.4	2	100
			2879.25	7169.34	73.3	1	100
	12.1	7321.7	2595.00	7334.27	102.3	2	100
			2879.25	7169.34	73.2	1	100
						3	84.2

In this paper, the minimum externally tangent cuboids of the inundated roadways are used to mark the inrush water area. The inrush water areas are respectively expressed by the coordinates of the two diagonal points as shown in Fig.7a. In Table 1, we can draw the conclusion that under the condition of different inrush water radius, different parts of the roadway inundated at different time: when the inrush water radius is 30m, the two roadways affected by the inrush water submerged in 0.6h and 6.2h of time, respectively. While ascertaining the inundated are, the water filling status of the roadways are recorded. 0.6h after the inrush water took place, the fullness ratio for roadway 1 and 2 are respectively 10.8% and 6%. For roadways whose inrush water radius are respectively 60m and 90m, full inundation took place 3 and 4 unit of time, respectively. When the location of inrush water affected area within the roadway is made, it is easy to find out the corresponding inundation time, the volume of filling water and the status of this specific area. These kinds of information are of great importance for fast and efficient determination of risk-avoidance path on a daily basis.

V. CONCLUSIONS

(1) Application of 3D simulation techniques in inrush water process simulation contributes to efficient reflection of the actual situation in the sense of both time and space. Deduction conducted by the octant searching ellipse upon the inrush water is also in agreement with the real situation. This searching method has now been applied in domestic mining software DIMINE.

(2) During the simulation, the size of the block and the searching ellipse must be decided rationally. An overestimated size for the block or the searching ellipse will only lead to partial reflection of the flow path of the inrush water within the roadway, while an underestimated size will make the deduction and calculation prohibitively heavy for the computer.

(3) In future research, emphasis should be given to simulation of inrush water process that takes into consideration of the actual roadway characteristics, roadway resistance and crevices and cracks. And the simulation should be conducted under speed-variable inrush water.

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