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Establishment of spatiotemporal dynamic model for water inrush spreading processes in underground mining operations

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ABSTRACT

Underground mine water inrush accidents are currently one of the most frequent forms of disaster in the mining industry. In order to develop and implement and effective rescue and avoidance plan for water inrush accidents in underground mining projects, this paper proposes a spatiotemporal dynamic three-dimensional (3D) model for the real simulation of the flow spreading process. A spatiotemporal dynamic model framework was developed through an analysis of the factors influencing temporal changes of water inrush spreading in roadways. The basis of the model is the generation of a roadway space network system, the core of the model involves the paths resolving for the water inrush spread processes, and the key of the model consists of the velocity and time resolving for water inrush spread processes. A roadway space network system was generated from roadway data modeling, regularization, arc drift straightening and 3D networking. The result is the spatial illustration of model. A spatial dynamic demonstration model was created with the information gleaned from the resolution of the paths of water spread down as well as water level rising in the roadway space network. A temporal dynamic expression of the model was then created from an examination of the hydraulic characteristics of the water inrush current, and the calculation of the velocity and time of water inrush spread. The feasibility and validity of the spatiotemporal dynamic model for water inrush spread processes was tested and verified through a case study.

1. Introduction

Underground mine water inrush accidents are one of the most frequent forms of accidents in the mining industry (Chen et al., 2012; He and Song, 2012). These types of incidents can result in tremendous pain and loss for individuals and for mining enterprises, and can negatively affect mining communities and general social harmony (Chen et al., 2010). For example, 121 people died in a water inrush accident that occurred at Daxing Coal Mine in Guangdong Province in China on August 7th, 2005, and 36 people lost their lives in another water inrush accident that took place at Wangjialing mine in Shanxi province in China on March 28th 2010. According to incomplete statistics, more than 500 water inrush accidents have occurred in China since 2000, with death tolls having reached as high as 3000. As the levels of underground mining increase in terms of intensity and depth, certain phenomena (such as high karst water pressure, high geostress, and strong mining disturbances) contribute to the rising danger of underground mine flooding. Consequently, in order to ensure mine safety, finding ways to prevent this type of disaster is of utmost importance (Wang and Song, 1999; Harteis and Dolinar, 2006). Through detection, observation, monitoring, analysis and the experimental study of underground mine water inrush, mine safety scholars have made significant progress towards understanding the mechanisms involved in mine water inrush (Guo et al., 2006; Oda, 1986; Wu et al., 2009; Li et al., 1996), discrimination of water sources (Li et al., 2008; Gong et al., 2008), risk assessment and prediction of water inrush (Zhang, 2005; Tang et al., 2002), and numerical simulation of water inrush mechanics and yield (Zhang and Shen, 2004; Yuan and Harrison, 2004; Wang and Park, 2002; Wu et al., 2008; Liu et al., 2009). However, the complex causes that lead to water inrush are not yet fully understood. The reasons leading to the phenomenon include objective factors such as the occurrence of ore and the hydrogeological environment, as well as subjective factors that result from human operations and management. Therefore, it is essential to develop programs based on effective strategies that aim to avoid water inrush accidents, and also to have contingencies in place for surface emergency personnel to effect a timely rescue when needed (Wu and Guan, 2006).

With this in mind, this paper discusses a spatiotemporal dynamic model for the water inrush spread process in underground

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Nomenclature

General, graph-theoretic notation

d	the path length for water spreading down
e	the starting point for water level rising and the end point of water spreading down
G	the set for all key points' information in roadway; created for water "spread"
$G1$	the set for all key points' information in the roadway; created for water "rise"
H	the set of current water level
h	the water resource level
K	the set of current "spread" hydraulic head nodes
$K1$	the set of current "rise" hydraulic head dots
$P(p, d)$	the set of "spread" paths
$P1(p, d)$	the set of "rise" paths
p	the key points that are passed by water spreading down
S	the set of initial "spread" dots
$S1$	the set of initial "rise" dots
T	the water inrush point

Variables defined in formulas

A	flooded cross-section area
C	Chézy coefficient
g	gravitational acceleration,
hf	the frictional hydraulic head loss
h	height of shaft
J	bottom slope
l	frictional length
m	unit mass of water
n	Manning's roughness coefficient
Q	unit yield of water inrush
$Q1$	unit dewatering ability
R	hydraulic radius
t	unknown spread time for water level rising to any position
V	volume of roadway space
χ	wetted perimeter
λ	frictional resistance coefficient

mining. The aim is to express the dynamic development of the flow spread process on roadways over time after water inrush. Using a 3D dynamic visual simulation for the water inrush spread process, the extent of roadway water inrush spreading over a given timeline, the spatial scope of affected roadways, and the degree of impact can be viewed directly, analyzed and judged. It is hoped that the findings will provide significant information that can be used to effectively formulate strategies to help avoid future water disasters as well as assist surface staff in the process of emergency rescues when needed.

2. The structure of the spatiotemporal dynamic model for the water inrush process

In order to effectively guide the formulation and implementation of strategies for the avoidance of water disasters and rescue situations in underground mining, the spatiotemporal dynamic model for the water inrush spread process needs to realistically simulate the spatial and temporal dynamic changes in the water spread process. After mine water inrush accidents, water pours into the roadway from water inrush points, and then flows to the bottom of the shaft along the roadway. As water continues inrushing, the water level in the flooded roadway keeps rising until it reaches equilibrium.

When facing water inrush accidents, both underground and surface staff should take into account their exact location in the roadway, the scope of the water inrush spread over a given timeline, as well as the water spread location and tendency over a subsequent time period. Therefore, in order to simulate the spatiotemporal changes of the water spread process, the simulation must take into account water spreading down the roadway from the start of the underground water inrush, followed by the process of the water level rising after a certain point in time, and finally the effects of dewatering and drainage on water spread during above processes.

There are four main factors influencing the spatiotemporal changes involved in water inrush spread in a roadway: the location of the water inrush points, the level and yield of the water sources, the spatial properties of the underground construction (such as spatial scale, spatial distribution, topological relations and hydraulic conductivity), and mine dewatering and drainage capacity. The locations of the water inrush points affect the water inrush in a roadway in terms of the sequence of spread paths. The level and yield of the water sources influences the scope and degree of the flood, as well as the final water level in a flooded shaft. The spatial properties of the underground construction then determine the sequence of spread paths of the water inrush currents in the roadway, as well as the scope and degree of the flood. Mine dewatering and drainage capacity can decrease water spread and control the extent of the water hazard. The spatial properties of the underground construction and mine dewatering and drainage capacity are known for each specific mine. However, the location of the water inrush points and the level and yield of the water sources are unique to each water inrush accident. The lack of knowledge and certainty with respect to these two factors has initiated a great deal of research (Noorishad et al., 1982; Lee and Nam, 2004; Zangerl et al., 2003). This study was initiated on the premise that the location of water inrush points as well as the level and yield of the water inrush resource are a known entity.

According to the analysis above, the establishment of the spatiotemporal dynamic model for water inrush processes is based on roadway space network system generation. The central core of the model is concerned with resolving paths of water inrush spread processes. The key to the model involves the determination of the velocity and time of water inrush spread processes. Fig. 1 shows the spatiotemporal dynamic model framework for water inrush processes.

The roadway space network system, which embodies the spatial properties of the spatiotemporal dynamic model for water inrush processes, defines the specific spread paths of water inrush. The procedures used to generate roadway space network system include roadway data modeling, roadway data regularization, arc drift straightening and roadway 3D networking. Once the four procedures are completed, a roadway 3D network system consisting of spatially directed graphs is generated.

Path resolving of water inrush spread processes determines the spacial dynamic effects of the spatiotemporal dynamic model during water inrush processes. Water inrush spread can be divided into two sub-processes: the water spreading downwards and the rise of the water level. Based on the generated roadway space network system, a study of the algorithm of both sub-processes within the system establishes the paths network of flow along the roadway.