International Journal of Mining Science and Technology 25 (2015) 1–6

Contents lists available at ScienceDirect

International Journal of Mining Science and Technology

journal homepage: www.elsevier.com/locate/ijmst

Topical areas of research needs in ground control – A state of the art review on coal mine ground control

Syd S. Peng *

West Virginia University, Morgantown 26506, USA

ARTICLE INFO

Article history:
Received 1 April 2014
Received in revised form 5 May 2014
Accepted 15 June 2014
Available online 7 February 2015

Keywords:
Ground control
Geology
Numerical modeling
Shield
Pillar

ABSTRACT

Ground control is one of the four subsystems of underground mining. It covers not only roof control, but also rib control, floor control, pillar design, shield design, overburden failures and subsidence. In the past three decades, ground control has made a tremendous advancement and many case studies have demonstrated its important role in the daily mining operations. However, there are plenty of room for improvements. This paper discusses the research needs in 12 subject areas including research approach, rock property, geology, computer modeling, in-situ stresses, roof bolting, coal pillars, field instrumentation, failures, surface subsidence, shield supports and coal bumps.

1. Introduction

The word "ground control" originated in coal mining literature in the 1950s. Back then it was used by a researcher as a general term related to the mechanics of roof control in coal mining. However, for some reasons, it was not accepted for common use. Rather the word "roof control" was most commonly used as a subsystem of underground coal mining (the other three subsystems being coal cutting, coal transportation, and mine ventilation). Roof control has been the popular terminology mainly because roof fatalities and injuries were due to failures of roof supports and these were the major hazards since the inception of coal mining. As coal mining continued and expanded into more geologically adverse and complicated reserves, problems other than roof failures arose. In the 1970s, the U.S. Bureau of Mines (the predecessor of the current Office of Mine Safety and Health Research (OMSHR) in the National Institute for Safety and Health or NIOSH) initiated research programs on "ground control." Ground control research covers not only roof control, but also rib control, floor control, pillar design, bump failures and subsidence, etc. The use of ground control greatly broadened the lines of thought when users encountered and attempted to solve the problems related to mining operations such that proper strategies and technologies could be developed to deal with the problems.

Just like rock mechanics, ground control employs the same theories developed for and commonly used in continuum mechanics. The major difference is that ground control deals with problems in mining operations, whereas rock mechanics deals mainly with rock properties, rock behaviors, and geotechnical issues in civil, petroleum and gas engineering.

Since mining deals with rocks and uses them as structural elements in their natural state, rock mechanics was quickly adopted in the mining engineering curriculum for application in the early 1960s. However, back then rock mechanics research was mainly concentrated on rock properties and rock behavior and could not fulfill the needs for mining operations, particularly in coal mining. So in 1981 the author of this paper initiated the Annual Conference on Ground Control in Mining (the title was changed in 1987 to the International Conference on Ground Control in Mining or ICGCM due to the strong interest and attendance from the international community). The conference was designed to promote the application of rock mechanics principles (actually the theories of continuum mechanics) to mining operations by providing a forum of information exchange among government researchers and regulators, university professors, equipment manufacturers, consultants, and related services professionals. Now in its 33rd year, the ICGCM has become the premium conference for introduction of new technology, networking, and in-depth face-to-face discussion on ground control. The conference is credited with making the mining community aware of what is available and subsequently helping the industry adopt them for improving safety and productivity. The papers presented at the conference are mainly application

* Corresponding author. Tel.: +1 3042933881.
E-mail address: syd.peng@mail.wvu.edu

http://dx.doi.org/10.1016/j.ijmst.2014.12.006
2095-2686/

oriented and as opposed to fundamental and theoretical developments.

A review of the 32 ICGCM proceedings published in the past 32 years and other related literature as well, indicate that ground control has become the common terminology in the mining industry; and that it has developed to become an inseparable part of mine design and problem solving tool for safe production.

There are many case studies that illustrated the application of ground control techniques for successful mine design and safe production and without it, the projects would have failed. In other words, ground control has advanced considerably in the past three decades. It has become an integral part of mine design which has helped dramatically improve both safety and productivity in the underground coal mine industry. However, there is still plenty of room for advancement and improvement, because of the challenges associated with the structural design of naturally occurring materials that must be utilized in their natural state of occurrence. Since they are not man-made, as in all other engineering disciplines, we lack the knowledge and techniques to determine the exact occurrence characteristics and behavior of the rock strata in their natural state. Furthermore we do not have the luxury of always choosing the best locations and we must design, support and build the mine structures with consideration of existing conditions. Consequently, the mine structures that ground control engineers build are subjected to a much higher level of uncertainty than those in other engineering disciplines which have the luxury of using man-made materials. Accordingly, the science of ground control has not advanced as quickly as most other engineering disciplines. In fact there is plenty of room for improvements in almost every topical area of ground control. A few basic problems that may result in serious consequences in ground control application are discussed in this paper [1–3].

2. Topical areas

2.1. Research approach

Currently the empirical approach for ground control in underground mines is very popular in the U.S. In this approach, methods of ground control design and ground control problem-solving techniques are derived from data collected from in-mine observations, written surveys and/or interviews of mine operators. Due to site specific issues and differences in an individual's perception or company's economic and safety standards regarding what is a "successful" or "unsuccessful" design and what constitutes "failure" of the ground control design, the survey results cannot be analyzed on an equal basis unless those factors are considered in the analysis. Therefore, the empirical approach tends to be a quick fix solution and should not always be considered as the final solution! Understanding both the mechanisms of ground control events and how a specific ground control technique works is the only way to advance the science of ground control.

"Research" by common understanding is to develop new knowledge, understanding and theories and for ground control in mining considerations to apply this information to the development of technologies, strategies and ultimately products that address the needs of the industry. In that light, most researchers tend to focus on what is currently popular and they forget or ignore past research results. We need to start from where our predecessors left off not repeating what they have done. Too often that is exactly what many current researchers have done.

2.2. Rock property

When I was in school for my advanced study in the 1960's, rock mechanics research concentrated mainly on the behavior (including failure and post-failure) of intact rocks in the laboratory. In the 1970's it expanded to rock mass study. However, due to the high cost, research on rock mass behavior did not go and has not gone very far. Therefore, in the past three decades, our knowledge about rock mass behavior has improved very little. Many basic issues we faced back then remain today.

(1) Relationship between the lab-determined properties of small samples and rock mass in the field are still relatively unknown. The current practice of using a reduction factor of 4–6 goes back to the late 1970's when this author began to use the 2D finite element models to simulate longwall shield performance. It is still commonly used today. This method is arbitrary although in most cases, the users claim to have verified the results by calibration with field data, i.e., back-calculation. Several other methods of determining the rock mass properties or extrapolating the lab-determined properties to the field cases have been developed. They tended to be site-specific or use too many factors that are not easily available or are determined relying very much on individual judgement.

(2) Rock/coal mechanical properties, mainly strength, determined in the lab is not a fixed number, rather it has a range, some of which are considerable. Traditionally and always invariably, an average value of those widely scattered strengths is used. Is this the best way? Shall we consider the distribution of strength? How will this affect the overall design?

(3) Time factor. This has been a completely ignored factor and yet it is one of the most important behavior factors. All rocks exhibit time-dependent behavior including failure, especially sedimentary strata associated with coal mining, and some are in fairly large in magnitude. But very few researches have considered this factor and practically no meaningful research on the topic has been done in the past 40 years. For instance, longwall shield leg pressure increases continuously over weekend idle time indicating that the roof strata subside with time, many cutters and/or roof falls in weak shale develop sometime after mining indicating that strata continue to move even after supports are installed, and the most interesting traditional practice in U.S. coal mines is that everything being equal the main pillars that are designed to serve the mine life are normally much larger than those in the production panels that last only a few weeks. Although some risk factor may have been considered, this practice recognizes the effect of time, i.e., pillar strength decrease with time, but why and how?

(4) Coal seams that are associated with thick and extensive weak rocks (e.g., clay shale and fireclay) are difficult to mine, because the entries developed in it are difficult and/or uneconomical to support. Many weak rocks absorb moisture and deteriorate with time, some very rapidly. Those weak rocks are difficult to prepare for rock property determination in the laboratory, because all recommended test methods of sample preparation required wet cutting and grinding and the weak rocks cannot survive the vigorous preparation. Therefore, specimen preparation techniques for weak rocks that are sensitive to moisture need to be developed.

2.3. Geology

(1) As stated previously, mine structures use rocks in their natural state as the building materials. We do not make it to our specifications as all other engineering disciplines do. We do not know in advance their rock mechanics properties and it becomes even more challenging since the rock