Woodhead Publishing Series in Energy

Advances in Coal Mine Ground Control

Edited by Syd S. Peng

WP
Woodhead Publishing

Woodhead Publishing Series in Energy

Advances in Coal Mine Ground Control

Edited by

Syd S. Peng

ELSEVIER

WP
WOODHEAD
PUBLISHING
An imprint of Elsevier

Woodhead Publishing is an imprint of Elsevier
The Officers' Mess Business Centre, Royston Road, Duxford, CB22 4QH, United Kingdom
50 Hampshire Street, 5th Floor, Cambridge, MA 02139, United States
The Boulevard, Langford Lane, Kidlington, OX5 1GB, United Kingdom

Notices

Knowledge and best practice in this field are constantly changing. As new research and experience broaden our understanding, changes in research methods, professional practices, or medical treatment may become necessary.

Practitioners and researchers must always rely on their own experience and knowledge in evaluating and using any information, methods, compounds, or experiments described herein. In using such information or methods they should be mindful of their own safety and the safety of others, including parties for whom they have a professional responsibility.

To the fullest extent of the law, neither the Publisher nor the authors, contributors, or editors, assume any liability for any injury and/or damage to persons or property as a matter of products liability, negligence or otherwise, or from any use or operation of any methods, products, instructions, or ideas contained in the material herein.

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library

Library of Congress Cataloging-in-Publication Data
A catalog record for this book is available from the Library of Congress

ISBN 978-0-08-101225-3 (print)
ISBN 978-0-08-101280-2 (online)

For information on all Woodhead Publishing publications
visit our website at https://www.elsevier.com/books-and-journals

Publisher: Joe Hayton
Acquisition Editor: Maria Convey
Editorial Project Manager: Charlotte Kent
Production Project Manager: Debasish Ghosh
Designer: Alan Studholme

Typeset by MPS Limited, Chennai, India

List of Contributors

Deepak Adhikary Commonwealth Scientific and Industrial Research Organisation (CSIRO), Kenmore, QLD, Australia

Thomas M. Barczak Principal Geotechnical Engineer, Mine Advice Pty Ltd, Newcastle, NSW, Australia

Yan L. Chen China University of Mining and Technology, Xuzhou, Jiangsu, P.R. China

Jingyi Cheng China University of Mining and Technology, Xuzhou, Jiangsu, China

Yang Daming Henan Polytechnic University, Jiaozuo, China

Dennis R. Dolinar The National Institute for Occupational Safety and Health (NIOSH), Pittsburgh, PA, United States

Bai Erhu Henan Polytechnic University, Jiaozuo, China

Russell Frith Consultant

Winton J. Gale Strata Control Technology, Wollongong, NSW, Australia

Hua Guo Commonwealth Scientific and Industrial Research Organisation (CSIRO), Kenmore, QLD, Australia

Yang Li China University of Mining and Technology Beijing, Beijing, China

Christopher Mark Pittsburgh Safety and Health Technology Center, Pittsburgh, PA, United States

Xie X. Miao China University of Mining and Technology, Xuzhou, Jiangsu, P.R. China

Syd S. Peng West Virginia University, Morgantown, WV, Slovak Republic

Qingdong Qu Commonwealth Scientific and Industrial Research Organisation (CSIRO), Kenmore, QLD, Australia

Daniel W.H. Su National Institute for Occupational Safety and Health, Pittsburgh, PA, United States

Stephen C. Tadolini Minova USA Inc, Georgetown, KY, United States

Chun-an Tang Dalian University of Technology, Dalian, China

Jiachen Wang China University of Mining and Technology Beijing, Beijing, China

Guo Wenbing Henan Polytechnic University, Jiaozuo, China

Yu Wu China University of Mining and Technology, Xuzhou, Jiangsu, P.R. China

Tao Xu Northeastern University, Shenyang, China

Hou Q. Zhang China University of Mining and Technology, Xuzhou, Jiangsu, P.R. China

Peter Zhang Alpha Natural Resources, Kingsport, TN, United States

Preface

It has been 10 years since the publication of my book *Coal Mine Ground Control*, 3rd edition, 2008. Since then, considerable advance has been made. So an update is due and this book presents some new developments or summary of developments that were not covered in my book.

This book consists of 13 chapters arranged in alphabetical order of the first author of the chapter. It was written by 24 authors from three countries, China, United States, and Australia—the top three coal producing and consuming countries in the world. The subjects include longwall mining, roof and cable bolts, pillar recovery in room and pillar mining, computer modeling, surface subsidence, and structural engineering approach in practical ground control. Among the nine chapters that deal with longwall mining, the major topical areas are overburden movement including failure and its effects on surface subsidence and groundwater flow, shield and tailgate standing supports, gateroad pillar behavior, design of predriven recovery rooms, and thick and ultra-thick seam mining.

Chapter 1 re-traces the research accomplishments on shield behavior and development of various tailgate standing supports that contributed to the success of longwall mining system in the United States by using the USBM's (now NIOSH) Mine Roof Simulator—the world's most powerful active longwall shield test machine; Chapter 2 reports on the latest developments on shield behavior research. In fact, it raises many questions regarding the conventional concepts about shield behavior and design; Chapter 3 expounds on the author's experience of the advantages of using the structural approach for practical ground control problems; Chapter 4 points out the importance to recognize the path of stress change in gateroad pillars due to longwall mining affects it strength; Chapter 5 demonstrates an integrated approach to investigate the behavior of longwall mining-induced strata, groundwater and gas flow, and presents case studies of the overburden strata response to longwall mining in Australia and China; Chapter 6 presents the state of the art of surface subsidence due to high production—high efficiency shallow thick seam longwall mining in China; Chapter 7 updates the MSHA's recent developments on safety guidelines for pillar extraction in room and pillar mining; Chapter 8 presents an effective in-mine testing method for bolt load and bolt length (free and anchored sections) of tensioned bolts; in Chapter 9, the author summarizes his lifetime experience in ground control projects that contributed greatly to the success of longwall mining operations for CONSOL including the latest developments on gas well chain pillar design; Chapter 10 describes the characteristics of cable bolt, its concept of design and new developments; Chapter 11 describes an FE computer program for failure of and gas flow in the bedded overburden due to longwall mining;

Chapter 12 presents the state of the art on thick (> 3.5 m) and ultra-thick (> 7 m) seams longwall mining in China; and Chapter 13 describe the author's experience in the design method for successful predriven longwall recovery rooms.

1. Barczak—Longwall standing support, shield
2. Cheng—Longwall shield
3. Frith—Structural engineering
4. Gale—Longwall failure on subsidence and water flow
5. Guo H—Longwall overburden
6. Guo WB—Subsidence
7. Mark—Pillar extraction
8. Miao—Roof bolting
9. Su—Longwall
10. Tadolini—Cable bolts
11. Tang—RFPA longwall overburden failure and gas flow
12. Wang and Li—Thick seam longwall
13. Zhang—Longwall recovery rooms

Syd S. Peng
January 2017, Morgantown, WV, United States

Contents

Research developments that contributed to the landscape of longwall roof support design over the past 25 years

1

Thomas M. Barczak

Chapter Outline

1.1 Introduction

Longwall mining has had a major impact on both productivity and safety in the US coal mining industry. Many changes have occurred as longwall mining matured from its infancy in the 1970s. Much of it was experienced based, but there were also focused research efforts that addressed all aspects of the longwall method.

Advances in Coal Mine Ground Control. DOI: http://dx.doi.org/10.1016/B978-0-08-101225-3.00001-3

Included in this was significant research dedicated to the ground control aspects. This paper summarizes a body of research conducted over a 25-year period that was concentrated on support technologies and support design, specifically investigations and research studies devoted to shield and gate road design.

1.2 The Mine Roof Simulator

The largest single investment ever made in ground control research was the Mine Roof Simulator (see Fig. 1.1). This unique load frame was designed and built by MTS Corporation to US Bureau of Mines specifications at a cost of approximately $10 million and was commissioned into service by the Department of Energy in 1981. The machine was designed with the primary goal of being able to test longwall shields under active loading that fully simulated the ground response associated with longwall mining. Constructing a load frame sufficiently large enough to accommodate a full-size shield and incorporating several "first-ever" operational capabilities provided this requirement.

Size: The load frame was fabricated with a 20 × 20 ft upper and lower platen and a maximum roof-to-floor height of 16 ft.

Loading capability: The longwall ground response required a multi-axis loading capability to simulate both the vertical convergence of the longwall face area and lateral movement of the mine roof from face toward the gob as the panel was extracted. The MRS

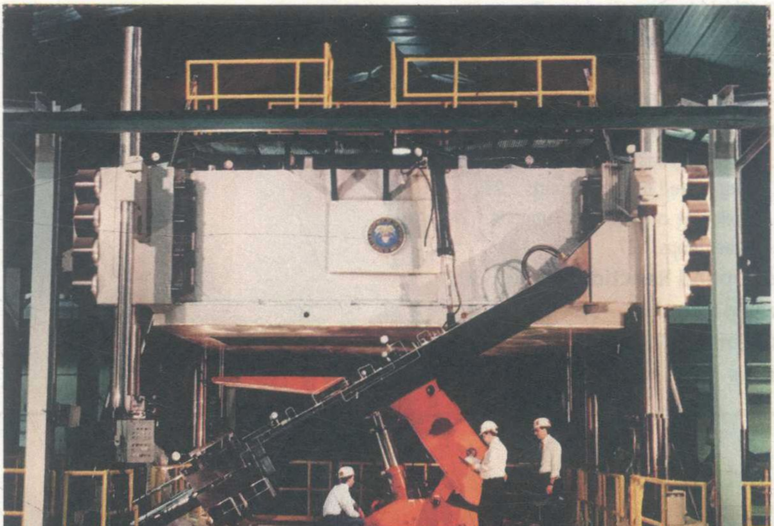

Figure 1.1 Mine Roof Simulator.

satisfies this biaxial loading requirement with the capability of providing up to 3,000,000 lbs of vertical force through a 24 in. stroke of the lower platen and up to 1,600,000 lbs of horizontal force through a 16 in. stroke of the lower platen. Rates of load application of up to 6 million lbs/min have been used. The maximum platen displacement is 5 in./min.

Load control: Precise load application is achieved by closed-loop servo-controlled actuators with six degrees of freedom control of the lower platen. The six degrees of freedom are three displacements (vertical, horizontal, and lateral) and three rotations (pitch, yaw, and roll). The pitch, yaw, and roll movements are commanded to keep the upper and lower platen parallel at all times during specimen testing. The lateral displacement is limited to 0.5 in. and exists primarily to maintain yaw control of the lower platen.

Control modes: The machine can be operated under either force or displacement control. Initially, an analog control system provided four vertical operating load ranges (200, 1000, 2000, and 3000 kips) and three horizontal load ranges (400, 800, and 1600 kips) and four vertical displacement ranges (5, 10, 20, and 24 in.) and four horizontal displacement ranges (2, 5, 10, and 16 in.). A fully digital control system replaced the analog system in 2009, which now provides load control to any specification within the full operational ranges.

Stiffness: The load frame stiffness when loading over small-area (2-ft-diameter) specimens with a load of 1000 kips in the middle of the platen is 25,000,000 lbs/in., which is similar in magnitude to a triaxial rock testing frame that has a stiffness of 60,000,000 lbs/in. Considering the size of the platens, this is a remarkable achievement. Furthermore, the platen deflection is measured and is incorporated into the feedback response allowing it to be subtracted from displacement control so that the intended displacement is maintained by the control system. The system also incorporates shock absorbers to absorb energy released during brittle specimen failure. The shock absorbers limit lower platen movement to less 0.1 in when sudden specimen failure occurs. These capabilities allow for testing of both stiff and soft specimens.

Since its commission in 1981, 7838 tests have been conducted in the MRS. The ability to test full-scale roof support structures under load conditions that replicate in-mine service loads has greatly enhanced the ability to fully develop roof support products prior to utilizing them underground, thereby eliminating the need for lengthy in-mine trials and accelerating the maturing of new roof support developments.

1.3 Longwall Shield Supports

Much of the success in the safety and productivity enhancements in longwall mining during the past 25 years can be attributed to the development of the shield support. The shield support provided unprecedented capacity and stability in a hydraulic support structure, and the basic structural design has been unchanged in the past 25 years.

1.3.1 Development of the two-leg shield

The development and maturity of the two-leg shield design changed the landscape of powered roof support design in longwall mining. The two-leg shield design

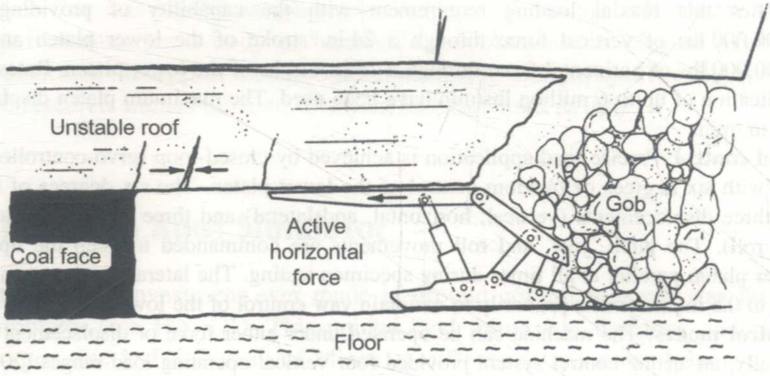

Figure 1.2 Active horizontal force with two-leg shield.

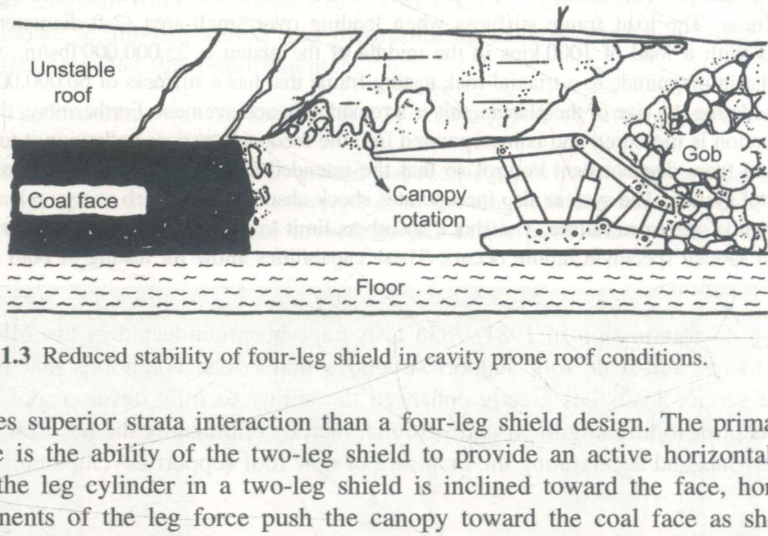

Figure 1.3 Reduced stability of four-leg shield in cavity prone roof conditions.

provides superior strata interaction than a four-leg shield design. The primary difference is the ability of the two-leg shield to provide an active horizontal force. Since the leg cylinder in a two-leg shield is inclined toward the face, horizontal components of the leg force push the canopy toward the coal face as shown in Fig. 1.2. This works to induce a force into the immediate strata attends to maintain the strata in a state of compression. In comparison, the legs of a four-leg shield are inclined in opposite directions to one another and the horizontal components of the leg force can cancel one another out resulting in no active horizontal force acting toward the coal face.

The unbalanced distribution of loading between the front and rear legs also make the four-leg shield less effective in cavity prone strata. As the example in Fig. 1.3 illustrates, the force in the rear legs causes the canopy to rotate up into the cavity, which causes a loss of roof contact at the canopy tip. This condition ultimately results in further cavity formation and requires the front legs to do most of the supporting work. Since the front legs of a four-leg shield are considerably smaller than they would be in a two-leg shield of equivalent support capacity, the four-leg shield provides much less supporting force than would a comparable two-leg design.

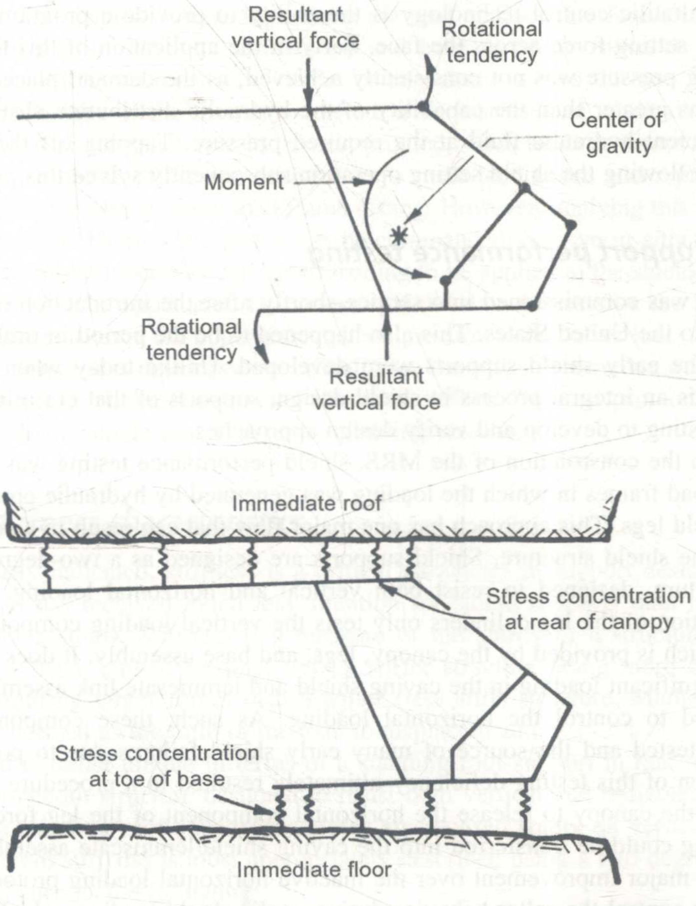

Figure 1.4 Resultant force actions on two-leg shield induce tendency for high toe loading on shield base.

The primary disadvantage of a two-leg shield is generally higher contact pressure on the canopy and base. High toe loading, caused by the moment created by the line of action of the resultant vertical forces acting on the canopy and base (see Fig. 1.4), can be a problem in high capacity two-leg shields and should be a primary consideration in the support design.

1.3.2 Control system technology

Enhancements in shield control have been made with the incorporation of electro-hydraulic control systems that automate the support function. Included in this technology development was the ability to incorporate a shearer-initiated shield advance capability, whereby the shearer location is sensed by a receiver on the shield and activates the advance cycle automatically. Another feature of the advancements in electro-hydraulic control technology is the ability to provide a programmable and consistent setting force across the face. Early in the application of this technology, full setting pressure was not consistently achieved, as the demand placed upon the system was greater than the capability of the hydraulic distribution system to provide sufficient hydraulic fluid at the required pressure. Tapping off the hydraulic pressure following the shield setting operation subsequently solved this problem.

1.3.3 Support performance testing

The MRS was commissioned into service shortly after the introduction of longwall mining into the United States. This also happened to be the period in time when the some of the early shield supports were developed. Unlike today when numerical modeling is an integral process in shield design, supports of that era relied heavily on load testing to develop and verify design approaches.

Prior to the construction of the MRS, shield performance testing was conducted in static load frames in which the loading was generated by hydraulic pressurization of the shield legs. This approach has one major flaw that can result in a poor assessment of the shield structure. Shield supports are designed as a two-degree of freedom structure, designed to resist both vertical and horizontal loading. Hydraulic pressurization of the leg cylinders only tests the vertical loading component of the shield, which is provided by the canopy, legs, and base assembly. It does not generate any significant loading in the caving shield and lemnicsate link assembly, which is designed to control the horizontal loading. As such, these components were largely untested and the source of many early shield failures due to poor design. Recognition of this testing deficiency ultimately resulted in a procedure of placing rollers on the canopy to release the horizontal component of the leg forces so that this loading could be transferred into the caving shield/lemniscate assembly. While this was a major improvement over the inactive horizontal loading protocol, it was difficult to control the roller behavior during cyclic shield loading, which was necessary to evaluate the fatigue aspects of the structural design.

The MRS solved this problem by providing active (externally applied) loading capability for longwall shield testing with the ability to provide both vertical and horizontal loading to the shield. The MRS can be programmed to allow the lower platen to essentially float (zero roof/floor friction test) so that the full horizontal component of the leg force (in a two-leg shield design) can be transferred to the caving shield/lemniscate assembly. This testing procedure is equivalent to the approach of placing rollers on the shield canopy in the static load frame method. The major advantage of this approach is that the test can be repeated through cyclic loading without any difficulty, unlike the roller test in the static frame, which generally requires constant adjustment of the rollers during cyclic loading.

The "zero-friction test" is the most severe horizontal load application because all of horizontal leg force is transmitted into the caving shield/lemniscate assembly. However, this loading caused by allowing the canopy to move forward (toward the coal face) with respect to the base produces a compression loading in the upper lemniscate link and a tensile force in the lower lemniscate link. This type of loading