and Underground Combined Mining Technology

露井联采技术

朱建明　刘宝宽　徐金海　刘宪权　吴吉南　冯锦艳　著

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内容简介

本书以平朔矿区在露井联采技术实施过程中出现的采动边坡稳定和边坡下巷道支护困难等问题为对象，采用现场勘察、室内试验、理论分析、现场检测和数值模拟相结合的研究方法，建立了基于塑性极限理论的采动边坡稳定性评价方法；提出了适合露井联采岩层移动特点的关键层模型；并对先井工后露天开采的安太堡南帮和先露天后井工开采的安家岭北帮两种典型工程背景进行了重点研究，提出了井工开切眼和停采线位置是控制露井联采时空规律的关键参数；最后针对布置在露采边坡下的三条井工大巷出现大面积冒顶、岩层移动以及采动边坡的治理等工程，提出了有效的工程防治对策。本书对指导露井联采矿区的安全生产和类似工程实践，具有十分重要的理论意义和工程实用价值。

本书是一部系统研究如何解决露井联采技术实施过程中出现的安全技术难题的专著，研究内容丰富，实践性强，可供采矿、地质、交通、国防、水利水电等相关专业的工程技术人员、科研人员及高校师生参考使用。

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前 言

中国是世界上少有的以煤炭作为主要能源的国家之一，2008 年我国原煤产量已达 27.16 亿 t，已经超过了世界总产量的三分之一，与煤炭生产相关的资源破坏、环境损害以及生产事故现象十分突出。因而我国学者率先提出了实现煤炭资源绿色开采的理念和科学研究的技术框架。煤矿绿色开采以及相应的绿色开采技术其基本概念就是从广义资源的角度认识和对待煤、瓦斯、水等一切可以利用的资源。基本出发点是防止或尽可能减轻开采煤炭对环境和其他资源的不良影响，目标是取得最佳的经济效益和社会效益。绿色开采的内涵是减少采煤对环境的破坏，为此就要形成一种使资源与环境相互协调的开采技术，同时应该提高矿产资源采出率，避免资源浪费。

我国地域辽阔，煤炭资源赋存状态多样，地质、地形条件不一，因此我国矿区开发类型呈多样化。归纳起来，主要有井工开采、露天开采、露天与井工联合开采（简称露井联采）三大类型。目前我国煤炭资源开发主要以井工开采为主，无论在矿井数量还是产量等方面均占 85% 以上。但纵观我国目前的煤炭开采格局，单一井工开采或露天开采一直是我国目前大多数矿区的开发模式。近年来，随着露井联采技术在平朔等矿区的大规模应用，露井联采的技术优势逐步显现。一方面，露采与井工联合开采能够充分发挥露天和井工开采的优势，提高资源采出率；另一方面，露井联采还将开采对环境的破坏程度减少到最低，实现资源与环境的协调开采。因此，露井联采技术将逐步成为我国浅埋煤层资源绿色开采的发展方向。

露天与井工开采技术的相互补充使得露井联采技术有如下特点：

(1) 利用露井联采可以解决露天开采的排土场问题。露天开采矿井排土场的选择越来越成为困扰露天矿发展的一个问题，如果排土场选择在非煤层区域，需要占用大量农田，同时花费昂贵的搬迁安置费用，而如果选择在煤层区域，则会造成压煤，使得通常情况下很大一部分资源无法开采。露井联采可以将土排在煤层区域，同时利用井工方式开采被排土场压着的煤炭资源，大大

节约了资源，提高资源采出率。

(2) 露井联采矿井可以减少露天排土场的距离。考虑到尽量少压资源，排土场到露天矿坑通常有一定的运输距离。而露井联采可以将排土场选择在露天矿附近，节约运输成本，同时露天矿排土运输工程中，产生的扬尘等造成的环境污染较大，而较短的排土距离可以减少对环境的污染。

(3) 露井联采技术可以减少对土地的破坏。通常排土场土壤贫瘠，结构不良，保水差，有机质含量低，因此在相当长的时间内不适宜大规模植物的生长；另一方面浅埋煤层的地下开采对上部地表土质影响较大，也会造成地表植被的破坏。露井联采可以将破坏造成的影响合二为一，因此可获得较大的环境效益和社会效益。

(4) 露井联采技术有利于露天矿内排土空间的安排。露天矿的排土场分为内排土场和外排土场，内排土场在露天矿的生产中具有举足轻重的作用，但内排土场的建设受开采工艺的制约。而露井联采中井工矿开采不管是对露天边坡压坡，还是对井工放顶煤需要的覆盖土层，都给露天矿提供了合理的内排土空间，因此可以借助露天矿的内排土实现露采与井工开采的互补，既解决了露天矿内排土场的选择问题又保证了井工矿的安全开采。

(5) 露井联采有利于排土场下浅埋“双硬”厚煤层的放顶煤开采。由于埋藏浅，“双硬”煤层放煤率一般在60%～70%左右，但由于露天开采的排土场产生的附加应力，使得井工开采的放煤率达到90%以上。

(6) 露井联采的初期投资相对于同样规模的露天矿山来说可以节省30%以上，并且其初期投资回收期短，开采效率高，提高了资金的使用效益。

由此可见，随着采矿工程技术的发展，露天开采与井工开采不再是相互独立、互为排斥的两种方法，而是可以在同一矿区同时并存、相互转化的两种相辅相成的开采方法。露井联采相对于单一的井工和露天开采能够较好地实现资源与环境相互协调，是浅埋煤层实现绿色开采的方向。

露井联采技术虽具有上述的优势，但在露井联采过程中也会造成露天与井工的相互干扰和影响。如井工开采将导致附近的露天边坡稳定性降低，露天煤矿平台将出现局部开裂、沉降，严重时将影响露天煤矿的正常运输；同时布置在露天边坡下的大巷将受到井工与露天复合开采的影响，存在边坡失稳导致大巷坍塌的严重安全隐患。因此，如何有效地发挥露天与井工开采的各自优势，将相互影响降到最低，实现露采和井工两个开采方法之间的协调开采是露井联采研究的主要课题，也是露井联采技术顺利应用的关键。

本书以我国亿吨煤炭基地之一的平朔矿区露井联采为研究背景，以浅埋水平厚煤层采用露井联采过程中出现的技术难题为出发点，采用现代研究手

段以及理论与实践相结合的方法，解决了平朔矿区水平厚煤层采用露井联采技术过程中出现的关键技术难题，使露井联采中露天边坡及边坡下大巷得到了很好的保护，同时也保证了露井联采矿井的安全高效生产。

本书在编写过程中得到了中国矿业大学（北京）王家臣教授的指导和帮助，并认真地审阅了本书的初稿，同时北京科技大学张宏涛博士、中国矿业大学（北京）孟宪锐教授对本书的部分研究工作提供了指导和帮助，在此一并表示衷心感谢，并对研究生陆游、周保精、吴剑平、侯跃华、成新元、张英和李泽荃等付出的辛勤劳动表示由衷的谢意。此外，本书的研究工作还得到其他科技人员的支持和参与，并参考了相关的项目研究报告以及文献资料，在此谨向课题组其他有关人员和文献作者表示衷心的感谢！

由于作者水平有限，有关参考文献较少，书中难免有不妥之处，敬请读者批评指正。希望本书的出版能起到抛砖引玉的作用，为实现我国浅埋煤炭资源的绿色开采做些贡献。

作　者

2009 年 8 月

PREFACE

China is among few countries that use coal as its dominant energy resources. In 2008 the raw coal output in China has amounted to 2. 716billion ton, accounting for over one thirds of total output in the world. Some problems related to coal mining are extremely prominent, such as, resources destruction, environmental damage, and production accidents. Thus, Chinese scholars took the lead in coming up with the concept of Green Mining of coal resources and technical framework and research for realizing the Green Mining.

The basic concept of coal resources Green Mining and relevant Green Mining technologies is to view and take coal, gas, water and all other useful resources in a broad sense as "resources". Its primary starting point is to prevent or play down as much as possible the adverse effect of mining on environment and other resources, and its goal is to maximize the economic and social benefits. What meant by Green Mining is to reduce the environmental damage of coal exploitation. Thus, it is a necessity to develop a kind of coal mining technology that harmonizes resources and environment and at the same time to boost resources recovery ratio so as to avoid resources waste.

Due to vast territory, diverse mode of coal resources occurrence and varied geological and terrain conditions, ways of exploring mining areas in China are diversified. To sum up, there are mainly three types, shaft mining, open—pit mining and open—pit and underground combined mining. At present, shaft mining is the dominant way of coal resources exploring in China, either in terms of mine quality or output, both accounting for more than 85% nationwide. But a brief overview over China's current coal mining pattern shows that most mine areas adopt either shaft mining or open—pit mining as their exploring way. In recent years, with the open—pit and underground combined mining technology widely used in Pingshuo mining area, advantages of this technology are emerging. On the one hand, it can combine the advantages of open—pit mining and shaft mining and improve resource recovery ratio. On the other hand, environmental damage will be reduced to a minimum level to achieve environment and resources coordination. Therefore, open—pit and underground combined mining will be the way where green mining of shallow seam coal resources is heading.

Given complementation of shaft and open—pit mining, open—pit and underground combined mining has following characteristics:

(1) Solving waste dump problem of open—pit mining. Waste dump site selection has become a problem which hinders the development of open—pit mines. If the site is located at non—coal zone, large area of farmland has to be occupied and colossal relocation costs is expected. While if it is located at coal zone, usually big chunk of coal resources will be buried under and can not be exploited. However, for open—pit and underground combined mining, dump site can be placed at coal zone and coal buried can be exploited with shaft mining. In this case resources will be saved and recovery ratio will be enhanced.

(2) Open—pit and underground combined mining can shorten the distance between mine and dump. In consideration of minimizing coal resources buried, there should be shorter distance between mine and dump. In open—pit and underground combined mining, the dump could be placed close to the mine, In this case, the transportation costs can be saved and environmental pollution can be alleviated since shorter distance would produce less dust compared with open—pit mining.

(3) Open—pit and underground combined mining can reduce damage to the land. Usually dump site is featured by barren soil, unsound structure, weak water holding capability and low content of organic substance. As a result, for a long time the land will be unfit for large—scale plant growth. On the other hand, shallow seam underground mining has enormous impact on upper soil and may result in the destruction of vegetation on ground surface. Open—pit and underground combined mining blended two damages into one, thus bringing greater environmental and economic benefits.

(4) Open—pit and underground combined mining helps to arrange the space of open—pit dump site. Open—pit dump site is classified into internal waste dump and external dump. The former takes a pivotal position in open—pit mine, but its construction is restricted by mining technology. In open—pit and underground combined mining, open—pit press slope and top—coal cover soil in shaft mining make reasonable room for internal dump. Thus using the internal waste dump in open—pit mine can realize the supplementation of open—pit mining and shaft mining, which not only solves the problem of internal waste dump but also guarantees the safety of shaft mining.

(5) Open－pit and underground combined mining is conducive for exploiting top coal, a heavy layer of hard coal and hard roof, buried under open－pit waste dump. Given shallow deposit, the drawing rate of 'two hard' layer of coal is generally 60～70%, but the additional pressure from waste dump can boost the coal drawing rate up to more than 90%.

(6) The initial investment of open－pit and underground combined mine is 30% less than open－pit mine. Meanwhile, the efficiency of fund utilization is improved greatly due to high exploration rate and shorter payoff period.

Thus, with the development of mining engineering technology, open－pit mining and shaft mining are no longer independent and mutually exclusive of each other, but coexistent at the same mine, and interchangeable and complimentary. Compared with open－pit mining and shaft mining separately, the open－pit－and－underground mining can achieve coordination between resources and environment, and is the course Green Mining of shallow seam coal will follow.

Although open－pit and underground combined mining has the above－mentioned advantages, it will also cause disturbance among open－pit and shaft mining. For example, shaft mining will reduce the slope stability of surrounding open－pit mine, which would result in open－pit platform collapse and subsidence, if serious, would affect the normal transportation of open－pit mine. At the same time, roadway under open－pit slope will be influenced by the combined excavation of open－pit and shaft mining, so that the hidden danger of roadway collapse is lurking due to slope instability. Therefore, how to take advantage of these two types of mining, minimize the disturbance and realize coordination is the major subject of open－pit and underground combined mining research and the key to its practical application.

Against the background of Pingshuo mine area, one of the 100 million tons coal base, the book takes the technical problems of open－pit and underground combined mining of thick seam coal at shallow horizontal level as starting point. By using modern research methods and integrating theory with practice, it solved above problems. The open－pit slope and main roadway under it are well－protected and safe efficient production is guaranteed.

In the process of preparing for this book Professor Wang Jiachen, who is from China University of Mining & Technology (Beijing), provides guidance and assistance as well as reviews the first draft of the book carefully. Dr. Zhang Hongtao from University of Science and Technology Beijing and Professor Meng Xianrui from China University

of Mining & Technology (Beijing) all provide guidance and assistance in part of the research work for the book. I would like to express my heartfelt gratitude to all of them.

In addition, Graduate students Lu You, Zhou Baojing, WU Jianping, Hou Yuehua, Cheng Xinyuan, Zhang Ying and Li Zequan contribute a lot for the book while other scientific and technical personnel give us support and participate in the research work as well as provide reference and relevant study reports for the book. I also owe my sincere gratitude to them for their hard work.

Due to the autho's limitation and inadequate bibliography, the book is liable to mistakes or omissions, suggestions for improvement will be gratefully received. Hope that the publication of this book can attract valuable opinions and contribute to the realization of shallow seam coal resources Green Mining.

Author

August 2009

目 录

CONTENTS

第1章 绪 论

1.1 露井联采定义及其分类

矿床埋藏较深而覆盖层较薄时，矿床的上部通常用露天开采，而矿床的下部则转为地下开采，简称为露天与地下联合开采。联合开采按其生产发展的情况，有如下三种开采方式：一是全面联合开采，是从设计（矿山生产）开始即考虑采用露天与地下同时开采；二是初期采用露天开采，生产若干年后转为地下开采，在露天转地下开采过渡时期的联合开采；三是初期采用地下开采，但因地下开采损失大或存在内因火灾等情况而转为露天开采，在地下开采转露天开采过渡时期的联合开采[1]。

按国内外矿山联合开采的时序关系，露天与井工联合开采又可以分为以下四类[2]：

(1) 先期进行地下井工开采，再进行浅部露天开采（井工转露采）。

(2) 先期露天开采浅部资源，再用井工进行深部开采（先露天后井工）。

(3) 露天与井工同期开采，即两种开采方法同期进行回采（露天与井工同时开采）。

(4) 露天或者井工开采后，转向其他的开采方式，形成露井复合型开采作业方式。

根据上述较为典型的露井联采定义及其分类的方法可以看出，以前研究的露井联采主要针对倾斜矿床（层），露天与井工开采存在上下的空间关系，其开采方式主要以先露天后转井工开采或先井工后转露天开采两种形式为主。由于煤层赋存条件的原因，其前后开采方式一般不同步，存在先后开采、分期管理的特点，尤其是两者在开采上不存在相互干扰，主要是后期开采要防止前期开采遗留的开采空间对其影响的问题，因此考虑问题比较单一，研究难度较小。目前我国非煤矿山对上述露井联采的研究方面积累了较为丰富的研究成果[3,4]。

随着露井联采方法应用范围的扩展，许多水平矿床（层），特别是一些浅埋水平厚煤层矿区也采用露井联采技术[5]，大大扩展了原露井联采的定义范围，使得原露井联采在定义和分类上出现一些误区，影响了露井联采的深入研究。文献[6]提出了按照开采煤层赋存情况以及井工矿、露天矿矿坑与排土场的空间形态，将露井联采分为两种类型：Ⅰ型露井联采和Ⅱ型露井联采。Ⅰ型露井联采煤层为倾斜煤层，浅部为露天开采，深部为井工开采。井工开采采煤沉陷的影响主要体现在对露天矿矿坑工作帮边坡及地表的影响。Ⅱ型露井联采煤层为近水平或缓倾煤层，端帮或排土场下井工开采，露采与井采基本上在同一

水平，且开采同时进行。整体边坡为外排土场—露天矿端帮所组成的复合边坡，加上井工开采的叠加，组成了一个空间形态多元化的复杂系统，井工开采不但影响上部排土场边坡的稳定，而且对矿坑、排土场总体边坡产生影响。我国目前开发的露天煤田大多为近水平或缓倾煤田，因此露井联采类型多为Ⅱ型，且多为第二种开采方式，即初期采用露天开采，生产若干年后转为地下开采。

我国"十一五"规划的13个亿吨煤炭基地之一平朔矿区，就是采用Ⅱ型露井联采模式，经过几年的应用，平朔矿区已从20年前单一的安太堡露天开采转变为露井联合开采的近亿吨的现代化煤炭生产基地，因此，本书以平朔矿区露井联采为研究背景，以近年来露井联采研究项目的成果为基础，提出了Ⅱ型露井联采在开采过程中遇到的实际问题以及具体的解决办法。

1.2 国内外露井联采技术研究进展

国外露井联采的矿山较多，如瑞典的基鲁纳瓦拉矿、南非的科菲丰坦金刚石矿、加拿大的基德格里克铜矿、芬兰的皮哈萨尔米铁矿、前苏联的阿巴岗斯基铁矿、澳大利亚的蒙特莱尔铜矿等[7,8]。江苏凤凰山铁矿是我国露井联采最早的矿山，随后相继有江苏的冶山铁矿、安徽的铜官山铜矿、湖北的红安萤石矿、甘肃的白银折腰铜矿、江西的良山铁矿、浙江的漓渚铁矿和山东的金岭铁矿等。目前，国内正在或即将进行露天与地下联合开采的矿山有江西的大新锰矿、河北的建龙铁矿、福建的连城锰矿、河南的银洞坡金矿、安徽的新桥硫铁矿、铜山铜矿和凤凰山铜矿、新疆的雅满苏铁矿、安徽的南山铁矿、四川的泸沽铁矿等。煤矿采用露井联采的矿山较少，主要有抚顺西露天矿、神东武家塔露天矿、依兰龙化露天矿、安家岭露天矿等。从上述分析可以看出，露井联采在非煤矿山开采已比较成熟，而在煤矿开采中使用和研究较少。

进入21世纪后，一方面因露天矿逐步转入井工开采，需要通过露井联采以形成相对稳定的产量规模；另一方面因深凹露天矿开采条件越来越差，剥采比大，采矿综合成本增加，需要采用露天与井工联合采矿技术以改善矿山经营效益。因此，越来越多的矿山将进行露井联采。特别是近年来，随着国产设备和放顶煤开采技术水平的提高，露井联采方式日益成为目前浅埋煤层高产、高效矿井的主要开采方式[9,10]。

长沙冶金设计研究院李鼎权(1994)[11]就指出在露井联采中需要解决露井开采的勘察和规划、露井联采的地压和边坡稳定、露井两者的有机结合、防洪排水等四个方面的技术问题。在上述四个问题中，地压和露井之间的协调关系是最关键的问题。

露井联采模式下，露天与井工之间的相互扰动，对露天边帮的破坏程度、范围，以及露天边坡下井工大巷的稳定性都具有很大的影响。对采动、边坡稳定的影响在水利工程和隧道工程中应用和研究较多。如在导流洞或泄洪洞对边坡稳定性的影响研究中，林正伟运用非线性有限元法模拟隧洞偏压问题十分突出的泄洪洞出口段开挖过程，分析了天然边坡和加固边坡条件下隧洞与边坡的相互作用机理；李建林[13]运用卸荷理论及其分析方