Research on Water-proof and Sand-proof Technology for Coal-mining in the Shallow Structure of Thick Loose-bed Overlying Area

厚松散层覆盖区浅部煤层开采防水防砂技术研究

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内容提要

在全面分析国内外水体下煤矿开采防治水(砂)技术现状的基础上,系统阐述了新生界第四系松散层的赋存状况及其含隔水性,利用大量勘探测试成果重点研究了松散层中“三隔”、“四含”和“基岩风化带”三个关键层的岩土工程地质特性,通过相似材料模拟和耦合数值模拟深入探讨了不同开采技术条件下的覆岩变形破坏规律、地下水流场特征和防水防砂的关键技术,在松散层水体下采煤实践中得到了验证和应用,取得了理想的应用效果。

本书可供从事矿业工程相关专业教学、科研和工程实践的技术人员阅读,也可供煤矿安全生产技术管理人员参考。

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前　言

能源消费支撑着经济发展，任何国家亦不例外。在我国，煤炭既是重要的基础性和战略性资源，也是化学工业的重要原料。新中国成立 60 多年来，煤炭在一次性能源消费构成中历来占 70%左右，而且在今后相当长时间内亦不会有太大的改变。特别是我国正处在工业化和城镇化的重要发展阶段，电力、钢铁、建材和化工等的耗煤量急剧攀升，对煤炭的需求量仍然比较大。

中国既是世界煤炭消费大国，也是世界最大的煤炭生产国，煤炭产量约占世界总产量的一半。国家煤炭工业“十二五”规划初步预测，2015 年我国煤炭需求量为 35 亿～38 亿 t。从目前煤炭开采实际来看，煤炭产量的增加一方面依靠新建矿井投产，另一方面则依靠老矿井挖潜。在老矿井挖潜方面，缩小新生界松散层水体下防水(砂)煤(岩)柱、提高开采上限已受到各煤矿企业的普遍重视，因为这部分煤炭资源埋藏浅、瓦斯威胁小，开采成本低。

我国华北型煤田多为厚松散层覆盖下的隐伏式煤田。以前，为了防止松散层水威胁煤矿安全生产，在煤矿设计时一般均留设了 50～100 m 不等的安全煤(岩)柱，从而积压了大量煤炭资源。仅苏鲁豫皖煤矿留设的松散层下防水(砂)煤柱储量就有 50 亿 t 之多，其中安徽两淮(淮南、淮北)煤田即达 15 亿 t，按目前两淮矿区四大煤矿集团(淮南、淮北、皖北、国投新集)总年产量估算，其防隔水(砂)煤柱资源的回收可使该矿区延长服务年限 10 年以上。因此，厚松散层水体下防隔水(砂)煤柱资源开采的防水防砂技术研究，既是减少煤炭资源浪费、提高资源回收率的必然要求，也是延长矿井服务年限、保证煤矿生产正常接替的客观需要。

上世纪 80 年代以来，淮南、淮北、皖北、新集、枣庄、焦作、峰峰、邢台、邯郸等矿区在浅部煤层提高上限试验开采方面做了大量的研究工作，进行了许多有益的探索和试采实践，取得了丰富成果和成功经验，推动了厚松散层覆盖区煤矿开采的技术进步。然而，近年来我国松散层水体下开采水害事故时有发生，淹采区、淹井等重大人员伤亡事故引起了社会广泛关注，说明松散层水体下煤矿开采的防水防砂关键技术仍没有被攻克。在提高开采上限过程中，由于安全高效的呼声越来越高涨，煤矿安全压力愈加突显，对防水防砂技术攻关的要求越来越迫切。就安徽淮北煤田而言，松散层水体下浅部煤层开采存在着多项技术难题——① 松散层厚至巨厚(60～500 m 不等)且发育多个含水层(第一、第二、第三、第四含水层，局部地区还发育第五含水层)，同时第四含水层(四含)通常直接覆盖在煤系地层之上，成为下伏煤层开采的直接充水水源；② 可采煤层上覆基岩厚度薄至超薄，特别是在古地形低洼处覆岩厚度更小，局部地区几乎为零，使得开采工作面距离松散层底部含水层(底含)很近，存在较严重的涌水溃砂隐患；③ 基岩风化程度较高、强度低，自身承载能力很小，高地压几乎全部由支架支撑，在断层发育地段压架、冒顶、涌水溃砂通常同时发生；④ 松散层中第三含水层(三含)富水性强，在厚煤层放顶煤开采条件下由于一次采高较大，覆岩局部区域容易形

成剪切破坏，对“三含”下面的“三隔”稳定性遂形成挑战，“三含”亦构成浅部煤层开采的潜在威胁。

从全国发生过新生界松散层水害事故情况分析，其原因是——① 松散层底部含水层富水性强，开采前对其水文地质条件没有充分掌握，开采过程中发生涌水溃砂甚至造成灾害事故；② 对不同开采技术条件下的覆岩变形破坏规律没有准确把握，安全煤（岩）柱高度留设不合理，或盲目提高开采上限，从而导致水害或砂害事故；③ 对松散层水体下浅部煤层开采涌水溃砂机理认识不清，采掘过程中没有采取行之有效的防范措施。

煤矿开采实践表明，水体下采煤技术涉及多门学科领域，如采矿、地质和水文地质、地球物理勘探、岩石（体）力学、矿山测量、计算数学等，是一项包含着多项研究技术和研究内容的工作，如覆岩变形破坏规律研究、煤（岩）柱合理留设及安全性研究、地下水渗流场演变特征研究、采掘工作面安全生产工艺和技术措施研究以及先进的探测技术开发及应用研究等。针对复杂的开采技术条件，作为一部科技专著，本书主要从以下几方面开展重点研究并取得了相应研究成果。

1. 第四系松散层及其含、隔水层研究

松散层厚度与分布、岩性与结构、含水层与隔水层等是影响矿井充水和提高上限开采的关键因素。以淮北煤田为重点，结合煤矿补充勘探和取样测试成果，对第四系松散层区域地层分布及其含隔水层组地质水文地质条件进行系统研究，弄清松散层中“三隔”（第三隔水层）和“四含”两个关键层的沉积特征、矿物组成、水理特性等，正确评价“三隔”的阻隔水性能，并且在深入分析“四含”物性条件基础上探讨其沉积相及成因模式、富水性及渗透稳定性。

2. 基岩风化带工程岩组特征研究

基岩风化带，作为松散层水体下浅部煤层开采防水防砂的关键层，对其进行深入研究具有重要意义。在淮北煤田选择具有代表性的井田和采区有关基岩风化带勘探资料，通过比较分析，弄清其厚度分布规律。利用大量样品的岩矿分析及物理力学指标测试成果，分析研究基岩风化带的岩石矿物组成和工程岩组特征，科学评价其阻隔水砂性能和抑制采后覆岩垮落、裂缝发育高度的效果。

3. 大采高下覆岩变形破坏规律研究

水体下采煤所要解决的关键问题是最大垮落带和导水裂缝带高度的确定。特别是大采高放顶煤开采条件下，覆岩应力调整机制和变形破坏特征有别于薄煤层开采或厚煤层分层开采，目前为止尚无现成的经验公式对其进行定量计算。为此，本书在合理选取和修正岩石物理力学参数的基础上，利用相似材料模拟和耦合数值模拟技术，结合实际开采和钻探验证，弄清厚松散层和超薄覆岩条件下、厚松散层和厚覆岩条件下大采高放顶煤开采覆岩变形破坏规律以及最大垮落带、裂缝带的发育高度。

4. 不同开采方案下的涌水溃砂机理研究

松散层水体下浅部煤层开采有两种方案——一是“下行式”开采（即先采最浅部工作面，由浅入深依次开采下面的工作面）；二是“上行式”开采（即先采深部工作面，由深及浅依次开采上面的工作面），不同的开采方案覆岩应力传递特点和变形破坏规律有所差异，包括松散层“四含”在内的区域含水层渗流场时空演变特征也有差别。因此，研究中将利用“流—固”耦合数值模拟，分析研究相邻工作面相继开采及单一工作面开采过程中“四含”渗流场和孔

隙水压力的时空演化规律，探讨松散层水体下浅部煤层开采涌水溃砂机理。

5. 浅部煤层开采防水防砂技术研究

在弄清地质和水文地质条件及涌水溃砂机理的基础上，分析研究符合实际的防水防砂关键技术。如综合考虑多种影响因素，合理留设安全防水、防砂或防塌煤（岩）柱高度，既能有效防止水、砂向井下溃入，又能最大程度地回收煤炭资源；按照不同的开采技术条件改进开采工艺，加强顶板管理，控制覆岩垮落带和裂缝带的发育高度；依据相似材料模拟、数值模拟和现场测试成果，改造充水含水层的水文地质条件，既能减轻直接充水含水层地下水对井下安全开采的威胁，又能保护其他含水层（非直接充水含水层）免受采矿影响等。

本书内容共分四编十二章。写作分工如下：第一章由桂和荣执笔；第二章由宋晓梅、桂和荣、陈陆望执笔；第三章由桂和荣执笔；第四章第一节由桂和荣、林曼利、陈敏、宋晓梅、刘向红执笔，第二节由桂和荣、马杰、林曼利、陈松、彭位华、李致春、陈敏执笔，第三节由桂和荣、马杰、陈陆望执笔；第五章第一节由桂和荣、马杰、林曼利、李致春、彭位华、陈松、陈敏执笔，第二节由桂和荣执笔，第三、四、五节由桂和荣、陈陆望、秦源、宋晓梅执笔；第六章由桂和荣执笔；第七章由涂敏、桂和荣执笔；第八章第一、二、四节由桂和荣执笔，第三节由陈陆望执笔；第九章由陈陆望、秦源、桂和荣执笔；第十章由桂和荣执笔；第十一章第一节由桂和荣执笔，第二节由陈陆望、秦源、刘鑫、王茜执笔；第十二章由桂和荣执笔。全书由桂和荣统稿。

限于研究水平和条件，书中难免存在错误和不足之处，恳请读者批评指正。

作　者

二〇一五年六月

PREFACE

Energy consumption is the pillar supporting economic development of every country in the world. In China, coal is a basic and strategic resource as well as an important raw materials for chemical engineering. In the 60-some years since the founding of the People's Republic of China, coal has dominated 70% of the one-time energy consumption and will remain so for a long time in future. At present, China is at a critical point of industrialization and urbanization, the need for coal in power generation, steel production and chemical engineering is soaring and the demand for coal remains at a high level.

China is a major consumer of coal and, at the same time, a major coal producer of contributing about half to the global coal production. According to the preliminary prediction in the 12th Five-year Plan of the National Coal Industry, coal demand in China will reach 3.5～3.8 billion tons by 2015, which requires at least 4 billion tons of coal production to keep up with. Currently, production growth relies on opening of new mines and development of existing ones. For the latter approach, the authorities generally look for ways to narrow water/sand-proof coal/stone pillars in the waters of the Cenozoic loose beds and to upgrade mining limits, for the considerations of closer-to-the-ground coal reserves, smaller gas risks and lower production cost.

The mines in the North China are mainly concealed coalfields covered by thick loose beds. In the past, to keep production from the menace of the waters in the loose beds, safety coal/stone pillars of 50～100 meters were obligated at planning. This has led to a large conservation of coal resources. There is as much as 5 billion tons of coal reserves in the water/sand-proof coal pillars in coal mines in Jiangsu, Shandong and Anhui, among which 1.5 billion tons are in Anhui (Huainan and Huaibei). Considering the current annual production of the major four coal mining groups in Huainan and Huaibei (namely Huainan, Huaibei, Wanbei, Xinji), coal reserves in the water/sand-proof coal pillars can extend the service life of the coals mines by more than 10 years. Therefore, mining of the water/sand-proof coal pillars in the waters of thick loose beds answers the call for resource saving and energy efficiency, as well as to ensure orderly production in coal mines.

In the 1980s, a large amount of research was carried out in Huainan, Huaibei, North Anhui, Xinji, Zaozhuang, Jiaozuo, Fengfeng, Xingtai and Handan with focus on how to upgrade mining limit in shallow coal seams. Useful results and rich experiences were generated from the experiments and practices, promoting technology advancements in mining of thick loose-bed covered mines. In recent years, water disasters took place from time to time in loose-bed waters across the country's mining area, causing heavy casualties and economic losses and attracting wide social attention. This shows that the key water/sand-preventing technology has yet to be conquered in coal mining from loose-bed waters. When upgrading mining limit, there is an urgent need for water/sand-preventing technologies to achieve high production and efficiency and to ensure safety. In Huaibei, Anhui, there lies a number of technical challenges in coal mining from loose-bed waters. First of all, the loose strata are as thick as 60～500m, breeding several aquifers (such as 1^{st}, 2^{nd}, 3^{rd}, 4^{th} and even 5^{th} in local area). The 4^{th} aquifer is usually in direct contact over coal strata, being the direct water source for lower coal mining. Secondly, upper overlying bed rock is thin to ultra-thin. Especially in low-lying locations of ancient landform, overlying rock is even thinner as to zero in some places, where mining work face is very close to bottom aquifer in loose-bed seam with higher risk of water/sand burst. Thirdly, weathering of bed rock is heavy with low intensity for self-bearing. The high places are mostly supported by trestles. At faulting area, support crushing, roof fall and water/sand burst often happen at one time. Fourthly, water abundance is high in 3^{rd} loose-bed aquifer. Local parts are vulnerable to shear fracture in top coal caving. This poses challenges to the stability of the 3^{rd} aquiclude under the 3^{rd} aquifer, making the 3^{rd} aquifer a potential risk to shallow coal mining.

The causes of water disaster in Cenozoic loose bed can be generalized as followings. Firstly, high water abundance in bottom aquifer in loose bed. Hydro-geological conditions were not fully understood before mining. Secondly, the deformation and destruction pattern of overlying rock was not accurately confirmed under different mining technologies. Safety coal/rock pillars were not verified or mining limit was upgraded without verification. Thirdly, limited understanding of water/sand burst in shallow coal mining in loose-bed waters coupled with insufficient prevention measure.

Coal mining practice demonstrates that underwater coal mining involves interdisciplinary technologies, such as coal mining, geology and hydro-geology, geophysical engineering, rock mechanics, mine survey, numerical mathematics, etc.. It also builds upon many research accomplishments, such as research on the deformation and destruction pattern of overlying rock, safety coal/rock pillar verification, underground seepage field characteristics, working techniques, and exploration technology. For the complicate mining technologies, this book will focus on the following research results.

Ⅰ. Quaternary loose-bed and aquifers and aquicludes imbedded

Loose-bed thickness, distribution, lithology and structure, aquifer and aquicludes are the key factors to water burst and mining limit. Take Huaibei as an example. Sampling and testing of the mines, research focused on the geological and hydro-geological conditions of the quaternary loose bed and imbedded aquifers and aquicludes. It was to study the sedimentation, mineral composition and hydraulic characteristics of the 3^{rd} aquiclude and 4^{th} aquifer and to accurately evaluate the water resistance of the 3^{rd} aquiclude. On the basis of though analysis of 4^{th} aquifer, discussion was carried out on its sedimentation, formation, water abundance and seepage stability.

Ⅱ. Lithology research of weathering zone in bed rock

Weathering bed rock, as a key layer of water/sand-prevention in shallow coal mining, bears importance for research and study. Through compare and comparison of typical coal mines in Huaibei, thickness distribution was studied and understood. From a large amount of sample analysis and mechanical index, lithology research of weathering bed rock was to evaluate scientifically the mineral composition and characteristics, as an effort to prevent water/sand burst and roof fall.

Ⅲ. Research on deformation and destruction pattern of overlying rock

The key issue in underwater coal mining is the maximum height of roof fall zone. Especially of top coal caving, the responsive mechanism of overlying rock and its deformation and destruction pattern are different from that of thin coal seams mining or stratified mining of thick coal seams. So far, quantitative calculation has not been identified. Therefore, this book selected working parameters and used similar material simulation and coupled numerical simulation to understand the patterns of deformation and destruction as well as the heights of roof fall and fissure zones under the conditions of thick loose-bed, ultra-thin overlying rock, thick loose-bed and thick overlying rock.

Ⅳ. Mechanism of water/sand burst in different mining projects

There are majorly two plans of underwater shallow coal mining in loose-bed. One is the top-down approach (from the upper to lower working faces). The other one is bottom-up approach (from the lower to the upper working faces). In different mining plans, differences exist in responsive mechanism of the overlying rock and the deformation and destruction pattern, including the evolution of the seepage field in the regional aquifer. Therefore, the research applied liquid-solid interaction numerical simulation, analyzing 4^{th} aquifer seepage field and water pressure changes and discussing water/sand burst mechanism in underwater shallow coal mining in loose-bed.

Ⅴ. Water/sand-prevention in shallow coal mining

On the basis of understanding hydro-geologicalconditions and water/sand burst mechanism, analysis was further conducted for practical water/sand-preventing techniques. For example, comprehensive consideration of multiple factors, safety pillar verification to prevent water and sand and to recycle coal resources to the maximum. To improve techniques for varying mining technologies, including reinforcing roof, controlling roof fall and the height of fissure zone. From the results of similar material simulation, numerical simulation and field testing, to modify the hydro-geological conditions of aquifer, in which way will lower risk of aquifer and protect other aquifers (non-direct contacting aquifer) from mining.

This book is divided into four parts and twelve chapters. Chapter 1 is authored by Gui Herong. Chapter 2 by Song Xiaomei, Gui Herong and Chen Luwang. Chapter 3 by Gui

Herong. Chapter 4. 1 by Gui Herong, Lin Manli, Chen Min, Song Xiaomei and Liu Xianghong. Chapter 4. 2 by Gui Herong, Ma Jie, Lin Manli, Chen Song, Peng Weihua, Li Zhichun and Chen Min. Chapter 4. 3 by Gui Herong, Ma Jie and Chen Luwang. Chapter 5. 1 by Gui Herong, Ma Jie, Lin Manli, Li Zhichun, Peng Weihua, Chen Song and Chen Min. Chapter 5. 2 by Gui Herong. Chapter 5. 3, 5. 4 and 5. 5 by Gui Herong, Chen Luwang, Qin Yuan and Song Xiaomei. Chapter 6 by Gui Herong. Chapter 7 by Tu Min and Gui Herong. Chapter 8. 1, 8. 2 and 8. 4 by Gui Herong. Chapter 8. 3 by Chen Luwang. Chapter 9 by Chen Luwang, Qin Yuan and Gui Herong. Chapter 10 by Gui Herong. Chapter 11. 1 by Gui Herong. Chapter 11. 2 by Chen Luwang, Qin Yuan, Liu Xin and Wang Xi. The whole book is complied by Gui Herong.

Due to research limitations, mistakes and inappropriateness are inevitable. We are looking forward to comments from the readers.

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第一编

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