BLASTING TECHNIQUE FOR CRACKED ROCK MASS

裂隙岩体爆破技术

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内 容 提 要

本书从岩体结构特征对爆破影响的观点出发，介绍了岩体工程地质特征及分类，岩体结构面特征与分形，裂隙岩体影响爆破应力波传播的规律以及岩体爆破结构效应；着重论述结构面产状、组数控制爆破效果和自由面存在的似固定梁弯曲破岩机理，论述硐室、深孔爆破动力学问题；较详细分析了爆破有自由面的应力状态和爆破效果，介绍了露天深孔梯段爆破、药室爆破和条形药包爆破等基本原理、设计方法、计算公式、药包布置、起爆顺序及施工技术；书中用较多的篇幅分析了裂隙岩体与地下工程中的围岩压力、巷道支护和巷道施工的关系以及防治危害的措施；论述了地震效应的特征和沟槽效应及震动判据；较详细的论述了岩体爆破计算机模型、爆破优化设计及专家系统；突出论述了露天深孔大区微差爆破的关键问题起爆方法和起爆顺序以及硐室爆破竖向双层多排药室分层爆破的问题。

本书可供冶金矿山、煤炭、地质、化工、建筑、建材、铁道、交通运输、水利电力、农田基建和国防等部门从事工程爆破的科研、设计和施工的工程技术人员以及大专院校有关专业的师生参考。

序　言

随着国民经济的迅速发展，工程爆破技术在现代化建设中起着日益重要的作用，爆破理论的研究工作取得了可喜的成果，广大爆破工作者在实践中取得了许多宝贵的经验。在实践中，人们认识到岩体的地质条件对爆破能的作用过程、对应力波和地震波的传播特性、对岩体爆破破坏机理和破碎效果均有显著的影响，在对节理裂隙岩体爆破技术的研究工作中，人们亦积累了许多有益的实践经验，但是目前还未见这方面的专著，对节理裂隙岩体爆破方面的论述，还只限于零散的论文的发表。

张志呈教授对节理裂隙岩体爆破技术进行了系统地研究，并在不同岩体、不同爆破类型的工程爆破中进行了试验和应用，取得了良好的爆破效果。作者根据多年的研究、实践和教学经验，并借鉴国内外爆破同行的研究资料，总结并编著了这本专著。书中对岩体的工程地质特性、岩体动力学效应、裂隙岩体爆破理论和爆破技术、裂隙岩体与地下工程等方面进行了比较全面系统地论述。

从本书内容的章节安排就可看到，该书表现了几个特点：

(1)突破了均质、连续岩体的深孔、硐室大量爆破的常规设计计算原则和理论，以非均质、非弹性、非连续性的裂隙岩体为原则，提出似固定梁弯曲理论，进而充实和完善了爆破理论。

(2)以裂隙岩体爆破理论为基础，对裂隙岩体爆破的机理分析、参数设计、安全计算、穿孔及爆破施工等方面进行了比较系统的论述。

(3)比较详细地讨论了工程爆破受控于工程地质条件的问题。

(4)深入地阐述了自由面与爆破效果的关系，为多层、多列大量爆破作用机理与设计提供较全面的依据。

(5)讨论节理面(结构面)强度及破裂条件，为露天和地下爆破方法的，选择提供依据，有利于露天边坡和坑下围岩的稳定。

(6)全面地讨论了大量爆破地质地形条件对爆破震动的影响。

(7)系统地讨论了计算机在工程爆破中的应用。

(8)对大量爆破相关的其它方面问题，也作了广泛的探讨。

这是一本理论联系实际的专著，论述了节理裂隙爆破技术，提供了裂隙岩体爆破参考资料，对广大读者定会有所帮助。这本书的出版发行，在爆破实践、科研和教学方面都会起到它应有的作用。

受本书作者张志呈教授的嘱托，当此出版发行之际，乐于向广大读者推荐，为之作序。

汪旭光

一九九八年十二月二十八日于北京

Preface

With the rapid development of national economy, the engineering blasting technology has played an important role in the construction of modernization day by day; research on the blasting technology has acquired encouraging achievements and in practice, numerous explosion workers have gained much precious experience. In practice, people have realized that geological conditions of rock mass have notable influence on the action process of blasting energy, the propagation characteristics of stress wave and seismic wave and the destructive mechanism and the crushing effect of rock mass explosions. During the research on blasting technology of joint crevice rock mass, people also have accumulated much beneficial experience in practice. But up till now, monographs concerning this aspect have not been published, exposition about the explosion of joint crevice rock mass has been limited and only some fragmentary papers have been published.

Professor Zhang Zhicheng researched on the blasting technology of joint crevice rock mass systematically, made experiments and application of engineering blast of different rock mass and different kinds of explosions, and gained good explosive effects. The author summarized and compiled this monograph basing on his long – time research, practice and teaching experience, using the research data of his colleagues and foreigners of the same occupation for reference. The book talks quite comprehensively and systematically about the engineering geological characteristics of rock mass, the effect of rock mass dynamics, the blasting theory and technology of crevice rock mass, the crevice rock mass and underground engineering, and so on.

Seen from arrangements of content and sections, the book has following characteristics:

I. Breaks through calculating principles and technology of the conventional design of homage, deep holes in continuous rock mass, much blast of room and puts forward the quasi – fixed beam bending technology, taking the anisotropy, discontinuous, and inelastic crevice rock mass as its rules. So it enriches and perfects the blasting theory.

II. Based on the blasting theory of crevice rock mass, talks quite systematically of aspects including mechanism analysis of crevice rock mass explosions, parametric designs, security calculation, perforation and blasting operation, etc. III. Discusses the problem that engineering explosions are controlled by engineering geological conditions in greater detail.

IV. Further elaborates on the relation between the free face and the explosive effect and provides all – out bases for action mechanism and designs of numerous multi – layer and multi – row explosions.

V. Discusses the strength and rupture conditions of the joint plane, i.e. the structural plane, and provides bases for choices of open – air and underground blasting methods, which will benefit the stabilization of open – air side slopes and under – hole country rocks.

VI. Discusses effects of geological and terrain conditions of large – scale explosions upon blasting shocks comprehensively.

VII. Discusses the application of computers to engineering explosion systematically.

VIII. Probes extensively into the other problems about massive explosions too.

This is a monograph with application of theory to practice. It talks about joint crevice blasting technology and provides data for crevice rock mass explosion, which will be bound to benefit the reading public. Certainly, the issue of the book will act on many aspects such as blasting practice, scientific research and teaching.

Entrusted by the author, Professor Zhang Zhicheng, I'm very glad to recommend this book to the reading public and to write the preface when it is published.

Wang Xugang

前　言

工程爆破长久以来广泛地应用于冶金、煤炭、建材、化工、核工业、水利水电、公路、铁路、港口、农林及国防工程。工程爆破技术，在国民经济建设中起着重要作用。即使在下世纪，工程爆破仍是完成巨大固体矿物开采和土石方开挖任务的有效手段。

几十年来，在爆破理论、控制爆破技术、岩石可爆性分级、爆破优化、安全技术、爆破量测技术，以及新型爆破器材等方面的研究工作取得了可喜的成果。大型工程的爆破实践更推动了该项技术的发展。尤其是改革开放以来，爆破技术与爆破器材、采掘工艺、矿山装备等方面相辅相成、竞相发展。矿山大型装备的出现，要求采掘、穿孔工艺实现高强度、高效率、高质量。而高威力的防水乳胶炸药、高精度多段微差雷管的应用，改善了爆破效果。通过实践，使我们对爆破技术本身系统性、特殊性、科学性的认识更加深化，对爆破技术与采掘技术间的相互依赖、相互促进关系更为明确。

在这日新月异的高科技时代，推动人们不断地去发现、去创新。但就爆破而言，仍然是以提高爆破破碎质量为核心。研究新型爆破器材；正确选择爆破参数，实现优化设计；改善经营管理，确保穿爆施工质量；推广应用 或进一步研究控制爆破技术，降低爆破有害效应，净化、美化采区环境。

从大的方面讲，控制岩体爆破效果主要是两个方面的因素：一是炸药的能量因素，二是岩体的特性因素。一般说来，炸药的能量因素，指炸药性质、孔网参数、装药结构、装药量、起爆方法和起爆顺序；岩体特性因素，包括岩体的物理力学性质，岩体中的节理裂隙分布、自由面的大小及数目等。这些因素中又都内含有可变因素和不可变因素，这就要在实际的设计施工中，根据不同不可变因素来调整可变因素。怎样使这两方面因素很好的结合，达到最好的爆破效果，这就是爆破技术的问题。

在研究和实践工作中，使我们深刻的认识到，爆破工程技术的发展，使得工程爆破与工程地质条件的关系更加密切。然而具体的爆破方法及地质条件岩体结构特征究竟如何影响或控制爆破及其效果还研究得很少，或未受到充分重视。我们知道，爆破作用下的岩体破坏与稳定问题，是动力破坏与稳定问题，是岩体中爆破激发应力波和岩体结构相互作用的问题。应力波导致岩体结构的变形破坏，而岩体结构又是制约应力波传播的重要因素。所以我们研究炸药爆炸激发的应力波，更要研究岩体的结构，对爆破的控制作用，尤其是各种岩体结构面在动载荷作用下的表现及对爆破方法和方案的选择，参数的确定和爆破工艺的影响。

过去很多人把这个问题作为岩石材料强度研究，实际上是脱离岩体地质实际的。作者多年的研究和实践发现，岩体爆破质量受岩体结构特征控制的作用，超过炸药性能对爆破的作用。

国外就岩体结构特征对爆破的影响研究较早，据不完全了解，40 年代的 obert；50 年代的 Duvell；60 年代的 ASH；70 年代的 Lareson and pagleise；1978 年美国马里兰大学和 80 年代初印度的 D·F·singh，k·s·sarma 等都作了较详细的试验研究。国内王鸿渠先生以及长江流域规划办公室、铁科院、水科院、冶金部、有色总公司的科研院所、西安理工大学、重庆大学和何恩为先生等，曾先后对岩体结构对爆破效果影响也作了大量工作。并都认识到岩体力学性质、岩体爆破效果是受岩体结构影响；但还没有完全掌握岩体力学效应规律与爆破岩体结构效应规律。这些问题长期得不到较广泛的共识。作者结合前人研究成果，初步归纳为：岩体工程地质特性；岩体性质与爆破分级；裂隙岩体中声波传播的规律；爆破岩体结构效应；自由面与爆破效果；岩体爆破破岩机理；岩石动力学；

裂隙岩体与地下工程;计算机在工程爆破中的应用;裂隙岩体爆破地震效应等问题来探讨。权作引玉之砖,供爆破界同仁参考、讨论。

本书可供从事爆破工作的研究人员和工程技术人员使用,也可供矿业、地质勘探和工程建筑等专业大专院校教师和学生参考。

对于目前的固体矿物开采和土石方开挖问题,根据有关资料表明,全球年搬运量约5000亿吨,其中约8成以上是露天采掘工程量,故本书编著中的裂隙岩体的爆破工艺,主要是针对露天开采工艺以及地下硐室、巷道掘进来进行论述的。

全书共分十五章,第一章、第二章介绍岩体工程地质特性、岩体结构类型及分类、岩体结构面特征与类型、岩体结构面分形与岩体工程地质分类和岩体强度特征对爆破的影响和分级;第三章论述裂隙岩体中声波传播规律、岩体结构面影响应力波传播特征;第四章爆破岩体结构效应论述结构面产状、组数控制爆破效果及实例;第五章论述岩石动力学;重点论述硐室和深孔爆破动力学问题;第六章论述有自由面存在的爆破机理、爆破应力波传播规律和效果;第七章论述裂隙岩体和宽孔距爆破破岩机理,提出了似固定梁弯曲破岩机理;第八、九、十章介绍露天深孔梯段爆破、药室爆破、条形药包爆破、裂隙岩体爆破参数设计和裂隙岩体爆破药包的布置、起爆顺序及实例;第十一章药室爆破施工技术主要包括装药、堵塞、起爆技术和爆破的组织管理工作;第十二章裂隙岩体与地下工程,突出论述地下工程岩体分级、节理岩体结构面强度及破裂条件,结构面与地下工程的稳定性、围岩压力、松软破碎围岩、大跨度巷道的施工及新奥法等;第十三章计算机在工程爆破中的应用,论述岩体爆破的计算机模拟、爆破优化设计及专家系统,以及岩体爆破效应的测定与预测;第十四章介绍爆破地震基本概念和传播规律、裂隙岩体爆破地震波特征,爆破地震波沟槽效应,爆破地震的评价;第十五章爆破规模,主要论述深孔大区多排微差爆破,深孔爆破爆破规模的确定原则及方法,竖向双层多排药室分层爆破存在的问题及原因分析,探讨了设计计算原则。

各章编写分工:第一章胡健,第二章、第五章肖正学,第十三章林秀英,第十四章郭学彬,第三章、第四章、第六章、第七章、第八章、第九章、第十章、第十一章、第十二章、第十五章张志呈。

中国工程院院士、中国爆破协会常务副理事长、北京矿冶研究总院副院长汪旭光(教授级高级工程师)为本书作序。在编写过程中还得到一些院校和单位同志的热情帮助,书中引用了鲜学福、王思敬、冯叔瑜、王鸿渠、高金石、侯云杰、林德余、秦明武、林韵梅、边克信、郑炳旭、高桐、陶振宇、廖先葵、吴子骏、黄苹苹、韩子荣、林学圣、朱瑞庚、孙清源、雷军、王文龙、邹定祥以及其他专家的资料,在此向他们表示诚挚的感谢。

由于编者水平有限,掌握资料有限,在写作过程中,具体章节文字都由多位作者分工执笔写成,虽然最后通过统一加工修正,但仍然不免挂一漏万。有不够系统之处、不全面之处、个人偏见和谬误之处,热诚地希望读者给以指正。

张志呈

一九九八年十月二十八日

Introduction

Engineering blast has been widely applied to metallurgy, coal, architectural materials, chemical industry, nuclear industry, water conservancy and hydroelectricity, roads, railways, harbors, agriculture, forests and national denseness engineering. The engineering blasting technology plays an important role in the construction of national economy. Even in the next century, engineering explosion is still an effective means of finishing mining huge solid minerals and fulfilling the task of excavating cubic meter of earth and stones.

For many decades, the research work has acquired encouraging achievements in the blasting theory, technology of controlling explosions, graduations of rock expandability, blasting optimization, The blasting practice of heavy construction greatly promoted the development of this item of technology. Especially after the reform and opening to the world, the blasting technology, together with blasting equipment, mining technology, mine equipment, etc. supplemented each other and developed competitively. The appearance of huge－size mine equipment required that the process of mining and piercing achieve high intensity, high efficiency and high quality. And the application of powerful dynamite with waterproof emulsion and the multistage detonators with high precision and elementary errors improved the explosive effect. Their, explicit.

In the age of high science and technology, which brings about new changes with each passing day, people are propelled forward to find out and bring forth－new ideas continuously. But in the case of blast, its core aim is still to increase the blasting crushing quality. So what we should do is to research new－type blasting equipment, to choose the explosion parameter correctly; to realize optimization design; to improve management; to ensure the construction quality of perforating explosions; to spread and apply or to research further on the controlling blasting technology; to decrease the harmful effect of explosions; to purify and beautify the environment of the mining areas.

Extensively speaking, there are two factors of controlling explosive effects of rock mass: one is the dynamite energy, the other is the characteristic of rock mass. Generally speaking, the former refers to the nature of dynamite, pore－net parameter, filling structure, filling quantity, the method of ignition and the sequence of ignition; the latter includes the physical－mechanics nature of rock mass, the distribution of joint crevices in rock mass, the size and number of free faces, etc. All of them contain changeable and unchangeable factors inside, so this requires adjusting the changeable factors based on the different unchangeable ones during the design and construction in practice. How to combine the factors of two sides well to achieve the best explosive effect is the problem of blasting technology.

During research and practice, we deeply realized that the development of the blasting engineering technology built closer relation between engineering explosions and engineering geological conditions. However, the research on how concrete blasting methods and geological conditions and

the structural characteristics of rock mass actually influenced or controlled explosions and effects, was quite little or was not taken seriously enough. We know that the problem of destruction and stabilization of rock mass under the blasting action is the problem of dynamic destruction and stabilization, is the problem of the interplay of stress wave stimulated by explosions and the structure of rock mass. The stress wave causes structural deformation and destruction of rock mass and the structure of rock mass and the structure of rock mass is also an important factor of constraining propagation of the stress wave. Therefore, we'll research on the stress wave stimulated by dynamite explosions; we'll also research on the controlling action of the structure of rock mass on explosions, especially on the expression and influences of various structural planes of rock mass under the action of dynamic loads on choices of blasting methods and schemes, determination of parameter and explosion engineering.

In the past, many people researched this problem regarding it as the strength of rock materials, which was indeed beyond the geological reality of rock mass. Through the long－time research and practice, we found out that the effect, which the blasting quality of rock mass was controlled by the structural characteristics of rock mass surpassed the effect of the dynamite nature on explosions.

Foreigners researched on the effects of the structural characteristics of rock mass on explosions rather earlier. According to the incomplete statistics, Obvert in 40's, Duvell in 50's, ASH in 60's, Lareson and Pagleise in 70's, the University of Maryland in America in 1978, D. F. Singh and K. S. Sarma in India in the early 80's, etc. conducted experiment and research on it in greater detail. In our China, Mr. Wang Hongqu, the Changjiang River Basin Planning Office, Railway Academy of Sciences, Water Academy of Sciences, Metallurgical Ministry, scientific research institutions of Non－ferrous Metal General Corporation, Xian University of Science and Engineering, Chongqing University and Mr. He Enwei, etc. also did much work on the influences of rock mass structure on explosive effects. All of them have realized that the nature of rock mass mechanics and the explosive effects of rock mass are affected by the structure of rock mass, but they have not mastered the effect law of rock mass mechanics and the structural effect law of exploded rock mass completely. These problems have not been universally agreed on. Combining with the predecessors' research results, we preliminarily made a conclusion and probed into the problems such as the engineering geological characteristics of rock mass, the nature of rock mass and classification of explosions, the law of sound wave propagating in the crevice rock mass, structural effects of exploded rock mass, free faces and explosive effects, the broken rock mechanism of rock mass blast, rock dynamics, crevice rock mass and underground engineering, the application of computers to engineering explosions, seismic effects of crevice rock mass blast. We want to use the book only as a minnow thrown out to catch a whale, and to provide it for the colleagues or people in the blasting circles to refer or to discuss.

This book can be applied to researchers, engineers and technicians working in explosions and can also be used as reference for the teachers and students of universities and colleges, majoring in mining industry, geological examination and engineering architecture.

As to the problems of present exploitation of and excavation of cubic meter of earth and stones, the concerned data indicate that the annual transport quantity in the word is about 500 billion tons, and about 80 percent of which is the engineering quantity of open mining. Therefore, the blasting

technology of crevice rock mass compiled in this book is mainly about the open mining technology, the underground room and heading advance.

The whole book is divided into fifteen chapters. The first two chapters introduces the engineering geological characteristics of rock mass, the structural types and classifications of rock mass, the characteristics and types of rock mass structural planes, the fractal of rock mass structural planes and the engineering, geological classification of rock mass, the effect of strength signature of rock mass on blast and its graduations. Chapter Three tells about the propagation laws of sound wave in crevice rock mass, propagation characteristics of stress wave affected by rock mass structural planes. Chapter Four is about structural effects of blasted rock mass and tells about the occurrence of structural planes, effects and examples of blast controlled by formation numbers. Chapter Five tells about rock dynamics, emphatically discussing the problems of room and deep – hole blasting dynamics. Chapter Six expounds the mechanism of blast with free faces, the propagation laws and effects of blasting stress wave. Chapter Seven tells about crevice rock mass and the breaking rock mechanism of broad – pitch explosions, putting forward the breaking rock mechanism of quasi – fixed beam bending. Chapter Eight, Nine and Ten introduce deep – hole stepped explosions, anther cell blast, explosions of bar – type medical bundles, the parameter design and the primers arrangement of crevice rock mass, the igniting sequence and examples. Chapter Eleven is about the engineering technology of anther cell blast, which mainly includes loading, plugging, and the igniting technology and the organizational management of explosions. Chapter Twelve is about the crevice rock mass and underground engineering, stressing the rock mass graduations of underground engineering, the strength and breaking conditions of joint rock mass structural planes, stability of structural planes and underground engineering, the pressure of wall rock, the loose fracture wall rock, the construction of large – span lanes and its new methods, etc. Chapter Thirteen is the application of computers to engineering explosions, discussing computer simulation of rock mass blast, the optimization design of blast and the expert system, determination and predetermination of rock mass blasting effects. Chapter Fourteen introduces the basic concept and propagation laws of explosion earthquake, the signatures and channel effects of the explosion seismic wave in crevice rock mass and the evaluation of explosion earthquake. Chapter Fifteen is about the explosive scale, mainly talking about the deep – hole, large – region and multi – row blast with elementary errors, the deterministic principles and methods of deep – hole explosive scale, analyzing the problems and reasons lying in slice blast of vertical, double – layer and multi – row anther cell and probing into the principles of design and calculation.

Compilation of the book is shared by following authors: Chapter One, Hu Jian; Chapter Two and Five, Xiao Zhengxue; Chapter Eleven, Lin Xiuying; Chapter Fourteen, Gao Xuebin; Charpter Three, Four, Six, Seven, Eight, Nine, Ten, Eleven, Twelve and Fifteen, Zhang Zhicheng.

Senior engineer (corresponding to a professor), academician of Chinese Engineering Academy, Wang Xuguang, who is the vice chairman of managing directors of Chinese Explosive Association and the vice president of Beijing Mining and Metallurgica General Research Institution, wrote a preface to the book. During the compilation, much warm – hearted help has been given by comrades in some other institutions and units. The book quotes data of many experts such as Xian Xuefu, Wang Sijing,

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Because there was a limit to the knowledge level of compilers and the mastered data, and because many authors wrote this book separately, we could not avoid imperfection of the book though we revised and corrected it unitedly. We hope enthusiastically that the readers will not spare their comments if they find that the book is not systematic or all－out enough and that the book has some personal prejudice and errors.

Zhang Zhicheng

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