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Fawu Wang · Tonglu Li (Eds)

Landslide Disaster Mitigation in Three Gorges Reservoir, China

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Editors
Dr. Fawu Wang
Kyoto University
Disaster Prevention Research Inst.
Research Centre on Landslides
Gokasho, Uji, Kyoto 611-0011
Japan
wangfw@landslide.dpri.kyoto-u.ac.jp

Prof. Tonglu Li
Chang'an University
School of Geological
Engineering and Geomatics
No.126 Yanta Road
Xi'an 710054
People's Republic of China
dcdgx08@chd.edu.cn

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Foreword

The purpose of the Three Gorges project is to construct a large dam, forming a large-scale water reservoir in the valley. When the final design reservoir water level is reached, the length of the reservoir will be longer than 660 km, which extends from the dam site at Sandouping town to Maoer-Xia Gorge in Chongqing City. The reservoir crosses the low–medium mountainous area consisting of the fold zone from Sinian system to Mesozoic Erathem, which is distributed in Hubei Province, Hunan Province, Yunnan Province and Chongqing City, to the low mountainous area formed by the fold zone ranging from the Triassic to the Jurassic Periods, which is distributed in the eastern part of Chongqing City. Generally, the reservoir area can be divided into two parts. The eastern part is from Sandouping town to Baidicheng in Fengjie County, with a length of 160 km. In this part, three portions consisting of limestone formed the narrow Three Gorges. Between the Three Gorges are two portions consisting of clastic rocks forming wide valleys. At the dam site are the Pre-Sinian System crystal rocks. In the Three Gorges parts, thick bulk limestone and dolomite are mainly distributed, sandwiching thin layers of sandstone and shale. The mountain height at the gorge areas is about 600–1,200 m, and the width at those areas is only 200–300 m. The geomorphology characterized by high mountains and deep valleys formed the famous three gorges, namely, Qutang Gorge in the west, Wu Gorge in the middle, and Xiling Gorge in the east. The Xiling Gorge is divided into eastern part and western part. The dam site is located between the eastern part and western part of Xiling Gorge. The upstream valley of the dam site consists of gneiss and mixture rock of the Pre-Sinian system, with 16-km long, wide valley. One of the two wide valley areas sandwiched by the three gorges is the Zigui basin valley formed in the Jurassic Period; the other was formed by shale during the Silurian Period. The width of the river in both areas is about 300–400 m, with a mountain height of 500–800 m. The slopes in these areas are relatively gentle. The western part extends from Baidicheng to Maoer-Xia Gorge, with a length of 490 km. It crosses the eastern part of the Sichuan–Chongqing basin, which features low mountains formed by fold zones during the Triassic to Jurassic Periods. The height of the mountain ridges is about 300–600 m, and the valley width is about 500–1,000 m. The bank slope height is about 100–300 m, with a gentle slope of 15–30°. In the part from Baidicheng to Fengdu County town, the length of which is 270 km, the Yangtze River flows along the axis of the Yunyang Syncline and the

Fengdu Anticline which consists of thick red sandstone and shale of the Jurassic Period. The bank slopes in this part are almost dip-structured slopes. In the part from Fengdu to the end of the reservoir, Maoer-Xia Gorge, the Yangtze River mainly crosses the northeast ward comb-style fold. When the river crosses the core part of the anticline which features limestone of the Triassic Period, small and short gorges were formed. These gorges distributed among the relatively wide valley. The main tributaries, such as the Daning-he River, Xiangxi-he River and Meixi-he River, are also in high mountains and steep gorges landscapes.

Meteorologically, the reservoir is located in the Western Hubei Province, and the Chongqing heavy rainfall area. The average annual precipitation is 1,100 mm. The rainfall generally concentrates in summer, and the maximum daily precipitation is between 150 and 240 mm. Also in summer, the rain likely continues for several days.

Summarizing the above features, the Three Gorges area has conducive environments of topography, geomorphology, rock mass structure, valley structure, and climate conditions for the formation of landslides. As a result, landslides have occurred in this area extensively. The major work to study the stability of bank slopes of the Three Gorges Reservoir is to investigate the landslide distribution in this area, and assess the stability of the bank slopes. In the regions with dense population such as towns and villages, and those parts with main traffic lines, it is especially important to investigate and study the large-scale landslides.

The investigation and research on large-scale landslides was emphasized from the first period when the pre-investigation of geology in the Three Gorges area for dam construction began in the 1950s. 1956–1967 was the first working period. Under the leadership of the Three Gorges Geological Team of the former Geology and Mineral Resource Ministry, and General Survey Team of Yangtze River Watershed Managing Office of Hydro-power Ministry (later the name was changed to Yangtze River Water Power Committee), members from Beijing College of Geology, Changchun College of Geology and Chengdu College of Geology participated in a 1:100,000-scale engineering geology survey in the reservoir area, and pointed out nine large-scale landslides such as the Xintan landslide, and five potential risky rock mass such as the Lianziya cliff. It is concluded that the part including the Xintan landslide and Lianziya cliff is a dangerous part with a low level of stability for bank slopes. The second time period dates from 1968 to 1983. The main work in this period was to conduct a detailed investigation in the above-mentioned dangerous part. The topographic survey and exploration was conducted by the General Survey Team of the Yangtze River Water Power Committee and the Hydrogeology and Engineering Geology Team of Hubei Province. The deformation monitoring was conducted by the Landslide and Rockfall Investigation Office of Xiling Gorge (established by Scientific and Technological Committee of Hubei Province). Thereafter, a deformation monitoring system was also established at the Huanglashi landslide, while other large-scale landslides with obvious deformation were undergoing monitoring for early warning. In 1985, the reactivation of the Xintan landslide was predicted successfully, and the loss caused by the landslide was mitigated to a very low level of occurrence. There was nobody killed by the landslide.

In 1982, the western part of the Baota landslide reactivated and formed the Jipazi landslide. In addition, Xintan landslide reactivated in 1985. Both of them formed major geo-hazards, and counter-measures to prevent further disaster should be implemented. There is especially the need for further discussion on the Three Gorges project itself. From 1983 to 1988, a period just before the dam construction, a new period started for the investigation of bank slope stability and landslides in the reservoir area. Counter measure works were conducted on the Jipazi landslide, the Xintan landslide, and the Lianziya risky cliff. From 1989 when the dam construction started, the exploration, monitoring, and counter measure works were continued. At the same time, landslide investigation works were also applied to a wider area including tributaries that have valleys characterized by relatively lower stability.

From 1983, the research on geology and earthquakes in the Three Gorges area, including bank slope stability assessment and landslide investigation, was reinforced by the Department of Environmental Geology, Ministry of Geology and Mineral Resource. The Hydrogeology and Engineering Geology Team of Hubei Province, Nanjiang Hydrogeology and Engineering Geology Team in Sichuan Province, Chengdu Center of Hydrogeology and Engineering Geology, General Survey Team of Yangtze River Water Power Committee, Landslide and Rockfall Investigation Office of Xiling Gorge of Hubei Province conducted excellent work. China University of Earth Science (Wuhan), Changchun College of Geology and Chengdu College of Geology actively participated in the landslide research in the area. From Changchun College of Geology, Guangjie Li, Mancao He, Jianping Chen, Lei Nie, Jingshan Bo, Chuanzheng Liu, Xinsheng Li, Huiming Bao, Dianqiang Chen, Fawu Wang, Tonglu Li, Yonggang Jia, Bingjian Ling, Minghui Liu, Hongjun Liu, Yan Liang, Tingkai Nian participated the field investigation and data analyses and obtained significant results. Notably, Mancao He completed the stability assessment of the Jipazi landslide, and his work was included in the final report. For the prediction of the Xintan landslide, Chuanzheng Liu estimated the sliding area and sliding mass volume, pointed out the sliding route and direction, and predicted the dangerous area correctly. His analysis was used for the final prediction, and an appreciation letter was sent to Changchun College of Geology from the Scientific and Technological Committee of Hubei Province.

Through nearly 40 years of investigation in the Three Gorges area, a general knowledge was established for the landslide distribution, and mechanism and the stability of the major landslides in this region. In the whole area, there are 392 landslides with a volume larger than 10,000 m^3. Among them, 57% (222 landslides) have high stability, 22% (88 landslides) have medium stability, and 21% (82 landslides) have low stability. Along the main stream of the Yangtze River in the reservoir area, there are 170 landslides and 86 rockfalls. Among the 170 landslides, there are 3 super large-scale landslides with volumes larger than 1×10^8 m^3, 29 large-scale landslides with volumes between $1\times10^7$and 1×10^8 m^3, 42 medium-large landslides with volumes between 1×10^6 m^3 and 1×10^7 m^3, 62 medium landslide with volumes between 1×10^5 and 1×10^6 m^3, and 34 small-scale landslides with volumes smaller than 1×10^5 m^3.

The three super large-scale landslides are the Fanjiaping landslide, the Gaojiazui landslide, and the Taibaiyan landslide. The Fanjiaping landslide is located 8 km

east of Badong County town, and has a volume of 1.1×10^8 m^3. The Gaojiazui landslide is located on the south bank near the Yunyang County town, and has a volume of 1.3×10^8 m^3. The Taibaiyan landslide is located near Wanzhou City, and has a volume of 1×10^8 m^3. All of the three super large-scale landslides were stable before water impoundment, and now they are also remaining stable after the current impoundment. Among the 29 large-scale landslides, there are 8 landslides with low stability. They are the Xintan landslide, Jipazi landslide, Huanglashi landslide, Daping landslide, the Zuojituo landslide, the Cicaotuo landslide, Sandengzi landslide, and Yunyang Chengxi landslide. The first three landslides, the Xintan landslide, Jipazi landslide, and Huanglashi landslide especially, also have high risk. Due to the counter measure works from the 1980s, their stabilities were improved greatly. For all of the eight large-scale landslides with low stability (due to their volumes) are between $1\times10^7$and 1×10^8 m^3, the workloads were quite heavy. Besides, the other 21 large-scale landslides along the main stream of the Yangtze River have relatively higher stability. They are remaining stable even after the current water impoundment. Among the medium large-scale landslides, medium-scale landslides and small-scale landslides, about 80% have higher stability. Only 20% of them have low stability. However, it is very important to pay attention to the dip-structure red-layer slopes distributed from Yunyang to Wanzhou, where large-scale landslides occurred frequently.

Among the 86 rockfalls along the main stream of the Yangtze River, there are 4 sites with large volumes. Three of them are located on the south bank of Wushan County town, and one is located near Wanzhou City town. The three large-scale rockfalls in Wushan are (1) the Baiheping rockfall with a volume of 4.6×10^7 m^3, which is the largest rockfall in the Three Gorges area, but was stable before the impoundment. It is also remaining stable after the current impoundment, (2) the Yaqianwan rockfall with a relatively smaller volume of 1.4×10^7 m^3. However, its stability is low, and rockfalls occasionally have occurred in this site. Close attention should be paid to this site; (3) the Dawan rockfall with a volume of 1,200 m^3. It is stable even after the current water impoundment. The rockfall located in Wanzhou City town is the Diaoyaping rockfall with a volume of 1.7×10^7 m^3. It is stable now and has low risk.

The most dangerous potential rockfall is the above-mentioned Lianziya rockfall, which is located on the south bank of the main stream of the Yangtze River. This cliff consists of limestone of the Carboniferous and Permian Periods. At the bottom of the limestone is a coal seam. The cliff facing the river is 700 m long and 200–250 m high. The limestone was cut by fissures and joints into many blocks. Among the risky rock blocks, South-1 block and South-2 block have a volume of 9×10^5 and 2×10^4 m^3, respectively. The possible fall locations are the valleys in the east side. Because they cannot fall directly into the river, the risk is relatively low. However, their fall will have negative influence on the North-3 block, which has a volume of 2.5×10^6 m^3. If South-1 and South-2 blocks fall down, the North-3 block will face the Yangtze River directly. The risk will be increased greatly, because the mountain structure here is a dip structure with a low angle of the coal seam, which is the potential sliding plane. Fortunately, the fissures in the rear part did not reach the

coal seam, and the North-3 block is also connected to the main mountain body. The possibility for the whole block sliding is relatively low. The most dangerous part of the cliff is the block cut by Fissure T9. This block has a volume of 1.2×10^6 m^3. It will slide into the main stream along a weak layer of carbonated shale. According to the deformation monitoring data, the monitoring point at the top of the Lianziya cliff moved north to the Yangtze River at an annual rate of 1.6 mm. The counter measure works on this potential rockfall were conducted before the water impoundment.

Now, the Three Gorges dam has been completed for 2 years, and the water level will reach the design water level, 175 m in 2009. The investigations of the landslide and risky rockmasses, and the monitoring and counter measure works are also ongoing. After the impoundment of the reservoir, some landslides were reactivated, and some slopes began to deform. It is also very important to conduct research and monitoring on the landsliding phenomenon for the purpose of disaster mitigation, and pay attention to the tsunami caused by the landslides.

My students, Fawu Wang and Tonglu Li, are trying to compile the research on landslides in this area in a book, written in English. It is a very significant work. This book reminded me of the active investigation life when I was young, and the time when I worked as a member of the National Expert Team on Geology and Earthquake for the project. I hope what we have done and what the young generation will do can contribute to the disaster mitigation in this important project.

I hope people have interest in the Three Gorges project could benefit from information found in this book. Also I would like to express appreciation for the kind support of the authors in this book and for their great contributions. For those who want to know more about the landslides in this region, I will like to recommend the Final Report on Geology and Earthquake submitted by National Expert Team for the Three Gorges project published in June 1988, the Comprehensive Report on Types of Bank Slope and their Stability in the Three Gorges dam reservoir finished by Chengdu Center on Hydrogeology and Engineering Geology, Nanjiang Hydrogeology and Engineering Geology Team of Sichuan Province, and Hubei Province Hydrogeology and Engineering Geology Team under the technical advice of the National Expert Team on Geology and Earthquake published in 1995.

Zhoudi Tan

Former Professor of Changchun College of Geology
October 2008, Changchun, China

Preface

The Yangtze River is the largest river in China, and the Three Gorges section is one of the most beautiful parts of the river. In order to harness the hydropower of the Yangtze River, a dream was envisioned by Mr. Sun Yat-Sen, the first president of China. In 1918, Sun Yat-Sen suggested in his book, Strategy for State, "a dam should be set here to let ships go downstream and use the water resource as power". Through the efforts of the Chinese people the dream came true after 100 years. Begun in 2004, the Three Gorges dam construction was completed in 2006, and the dam operation will become fully functional in 2009, when the reservoir water level will reach the maximum height of 175 m. Before the dam construction, the water level at the Three Gorges dam site was 90 m. An increase of 85 m of slowly rising water in a reservoir with a length of about 660 km from the dam to its terminus at Chongqing City has greatly impacted the environment. The impact on the geo-environment, especially the instability phenomenon and landslides, was given great attention, because landslides not only affect the people living on the bank slopes but also affect navigation and shipping on the river. In addition, the sliding masses moving into the reservoir will have negative effects on the lifetime of the reservoir itself. Because of the importance of this consideration, bank slope stability and landslide problems have been, and will continue to be studied systematically. The studies can be divided into two periods seperating in June 2003, when the first reservoir impoundment was conducted for partial operation. To summarize, the studies before the impoundment were concentrated on landslide site identification, and instability evaluation of existing landslides; while in the period after the impoundment, the studies shifted to landslide monitoring and prediction of landslides caused by water-level changes during the reservoir operation. The purposes of the studies for the two periods are the same, which is to acquire sufficient data and information for landslide disaster mitigation.

The idea to edit this book was initiated by the interest of non-Chinese colleagues. Whenever we presented our research in the Three Gorges area, others always wanted to know more. The Three Gorges area is a mysterious and challenging area for them. As a result, this book aims to present the landslide studies in the Three Gorges dam reservoir area for the two periods before and after the impoundment. Chinese experts on landslides learned much about landslides in this area as a result of the great project. It is very important to document these important experiences. A comparison

between the works before the impoundment and after the impoundment is also very interesting because the great change of the water level in the reservoir provides a dynamic challenge for the landslide disaster mitigation. This book will document the dynamics of slope failures and subsequent mitigation, providing a beginning for innovative ways to cope with the complexity of the problems.

In order for this book to present the real level of Chinese experts on landslides in this area, authors from different organizations were invited to contribute chapters. They are from Yangtze River Management Committee, Land and Resource Ministry, Chinese Academy of Sciences, and some major universities. All of these organizations are involved in the landslide studies in the Three Gorges area and have contributed to this book. We hope this book can represent the magnitude of the national-level research on landslides that is occurring in this important area.

In reference to the content, some chapters address regional characters of landslides, and some chapters present case studies. Some methodological studies with application to this area were also included. We believe that the scientific progress obtained from both the geologic and engineering practices are fully presented in this book.

Editing the book in English is a great adventure for our two Chinese editors, as we do not have lengthy experience in English-speaking countries. At this point, we would like to give our sincere appreciation to Ms. Lynn Highland of The United States Geological Survey. She made a trip to the Three Gorges area in 2007, and investigated some typical landslides. She checked all of the chapters, correcting for English usage and grammar. For some chapters, she made suggestions to authors to revise the chapter in order to make them more understandable. It is she who makes the book possible. Without her kind help, we would not be confident of whether our target readers, the people in western countries would fully understand it or not.

Finally, we would like to convey our appreciation for the financial support from MEXT, Japan, and NSFC, China, through the scientific research grants (No. JSPS-18403003, Project leader: Fawu Wang, and No. NSFC-40772181, project leader: Ping Li) and the technical support from Birke Dalia from Springer-Verlag.

Fawu Wang — Kyoto, Japan
Tonglu Li — Xi'an, China, October 2008

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