THE RESERVOIR INDUCED EARTHQUAKE

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内 容 提 要

本书汇集归纳了我国水库诱发地震的研究成果，参考了世界水库地震的资料，并在作者本人实践和研究的基础上，对水库诱发地震的主要问题进行了系统的阐述。

全书包括三个部分。第一部分为新丰江水库地震震例的全面介绍；第二部分为中国和世界水库诱发地震概述，并给出了世界水库诱发地震一览表；最后部分就若干理论及实践问题作了分析和探讨。

本书可供地震、地震工程、工程地质、水利水电工程、建筑设计等科技人员和有关院校师生参阅。

水库诱发地震

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序

地震是地球动力作用的产物。它可能是内动力引起的构造地震和火山地震，也可能是外动力造成的塌陷地震等。在一定的条件下，人类的工程活动可以诱发地震，诸如修建水库、城市和油田的抽水或注水、矿坑和矿井的崩塌，以及人工爆破和爆炸都能够引起当地出现异常的地震活动，统称诱发地震。这类地震的形成，一方面依赖于该区的地质条件、应力状态和有待释放的能量的积蓄程度等因素；另一方面也与工程行为是否改变了一定范围的应力场的平衡状态有密切的关系。一般说来，诱发地震的震级比较小，震源深度比较浅，对经济建设和社会生活的影响范围比较窄。但是，水库诱发地震则曾经在世界上多次导致破坏性后果。更有甚者，水库地震还经常威胁着水库大坝的安全，甚至酿成远比地震的直接破坏更加严重的次生灾难，其灾害程度和波及范围将远远超过地震的直接影响。故此，对水库诱发地震应予充分重视，绝不可掉以轻心。

我国拥有十分丰富的水利资源。据统计，自从新中国成立以来，全国已经修建了大小水库8万多座。无疑，今后仍将继续修建更多的水库，以便更充分地开发能源和造福人民。随着我国经济建设的发展和科学技术的进步，计划兴建和正在建设的水利工程的规模日益扩大。目前在长江和红水河的某些地段正在筹备修建特大型水库。我国和其他发展中国家将面临愈来愈多的水库地震问题是意料之中的事。这既向地震工作者提出了紧迫的要求和艰巨的任务，又为深入研究水库诱发地震的形成规律提供了更多的机会和有利条件。

全世界的地震学家正在通过不同的科学途径，努力探索地震的奥秘。这是需要几代科学家持续顽强奋斗才能有所突破的科学任务。水库诱发地震既有相同于一般地震活动的共性，又有其自身特有的属性。鉴于我国的经济建设正在蓬勃发展，一系列水库地震问题已经提出并将逐渐增多，自60年代起，中国的地质学家、地球物理学家、地震工程学家、大地测量学家以及许多学科的科学工作者，都投身到水库地震研究的行列。他们首先[illegible]东新丰江水库进行了多方面综合研究，对水库蓄水以后立即出现的地震活动进行分析，判断是否属于水库诱发地震，预测该区地震活动的发展趋势，并提出应采取的地震对策。后来，还对我国陆续出现的其他水库地震进行了类似的研究。科学家们还参与待建水库的选址工作，开展地震危险性分析，进行水库诱发地震的预测等等。总之，中国的水库地震研究始终紧紧围绕我国经济建设提出的实际问题，面向生产实际，服务于社会经济生活的需要。当然，中国的科学家并没有忽视水库地震的理论分析和实验工作，在这方面也取得了可喜的进展。水库地震研究的发展过程进一步证明，科技工作必须面向经济建设，经济建设也必须依赖科学技术。事实表明，凡是面向经济建设的科研工作，不仅可以得到经济建设的支持，科学本身也一定可以得到迅速发展。今天，中国的水库地震研究已积累了丰富的成果，受到国内外同行的重视和赞

赏。这是近三十年来几百位科技工作者劳动的结晶。本书的著者勇敢地挑起重担，对中国的水库地震研究成果进行了系统总结和全面介绍，同时还把国外研究成就一并作了介绍和分析。我相信，著者的贡献将有助于推动中国以至世界水库地震研究的发展，有利于水利工程建设和各项经济建设。为此向他们致以衷心的祝贺，并借以对本书加以推荐。

1988．5．20

Foreword

Earthquake may be caused by the dynamic effect of the earth, such as tectonic earthquake and volcanic earthquake. It can also be induced by external dynamic forces, such as collapse earthquake induced by weathering, erosion and raining. However, human activities play an important role in induced earthquakes increasingly, especially engineering activities under specified conditions, e.g. reservoir construction, pumping out of underground water or injection of water into the underground of a city or an oil field, collapse of a pit or a shaft in a mine and artificial explosion or bursting. These events, which are capable to induce abnormal earthquakes in the local area, are generally referred as induced earthquakes. The formation of this kind of earthquake depends on the factors, such as geological condition, strsess state and accumulated energy to be released in the local area on one hand, and, on the other hand, it relates closely to the balance state of stress field in a certain range which has been changed by engineering activities actually. Generally speaking, magnitude of induced earthquake is comparatively small, its focal depth is rather shallow and the range of effect on economics, construction and social life is rather narrow. However a lot of destructive earthquakes have been induced by reservoirs in the world. Furthermore, reservoir induced earthquake threatens the safty of the dam frequently, producing secondary disaster far more serious than the damage directly produced by ordinary earthquake, and its sequence and range of effect exceed those of ordinary earthquake. Therefore, full attention should be paid to the reservoir induced earthquake and it cannot be neglected absolutely.

There are abundant hydraulic resources in China. According to statistics, eighty thousand reservoirs, small and large, have been built since the establisment of New China. No doubt, more reservoirs will be built in the future al so that the energy source in China will be fully developed and more benifit will be obtained from reservoirs. At present extremely large-size reservoirs are prepared to be built at certain sites on the Yangtze River and the Red Water River. More and more problems about reservoir induced earthquake will be expected to encounter in China and other developing countries. Many reservoirs will be built on different geological environments

in such countries. Urgent demand and difficult task will be given to seismologists,and more chances and favourable conditions will be provided for the further study on formation of the reservoir induced earthquakes.

Seismologists of the world are devoting themselves to explore the mystery of earthquakes through different scientific approaches.The task needs scientists' continuous hard working in study for generations. Reservoir earthquakes have generality similar to common earthquakes,but they have their own features. Owing to the fact that the economic construction in China is developing prosperously and a series of problems on reservoir earthquakes have been raised increasingly, the Chinese geologists, geophysicists, earthquake engineers, geodetic surveyors and other scientists have devoted themselves to the study of induced earthquakes since the sixties. At first, they carried out comprehensive study on Xinfengjiang reservoir, Guangdong province, analyzing the seismic activities immediately occurred after filling, judging whether these were induced earthquakes or not, predicting the trend of future earthquakes in the reservoir area and suggesting some measures for earthquake resistance. Similar study was carried on for other reservoir earthquakes continually occurred later. Scientists participated site selection of reservoirs to be built, performed seismic risk analysis and reservoir earthquake prediction, etc. In short, study on reservoir earthquake was carried out in China around the practical problems in the economic constructon throughout, solving the practical problems in production and satisfying the need of the society.Of course,theoretical and experimental study were performed by Chinese sicientists, obtaining splendid results. Process in the study of reservoir earthquake shows further that scientific and technical work must face the economic construction, and, in return, economic construction has to depend on the scientific and technical work. At the same time, it is also shown by the fact, that scientific and technical work facing the economic construction not only can be supported by the economic construction, but developes rapidly for its own. Today, a lot of study results have been accumulated in China and full attention have been paid to them and greeted with applause by the foreign colleagues.These results are the crystals of labour of hundreds of Chinese scientists. In this book, study in the Chinese reservoir earthquakes is systematically sammarized and fully described,and achievements in the foreign study are also introduced by the authors. Contribution of the authors, I believe, will be helpful to the promotion and development of study on reservoir earthquake in China and even in the world, and benefit to the hydraulic engineering construction and other economic construction. Finally I

would like to congratulate the authors wholeheartedly for their contribution and recommend the book to the readers.

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May 20, 1988.

前　言

水库诱发地震是一种特殊类型的地震活动，它是由于水库蓄水而诱发的地震。它们紧邻水库和水坝，是衡量水库安全和大坝稳定性的重要因素。水库地震对人民生命和社会财富的威胁，包括由于地震活动直接产生的破坏，也包括由于毁坏水库、水坝和水电站所导致的间接损失，后者可以造成十分严重的影响，更不容忽视。我国已经发生13起水库诱发地震，世界其他国家也有一百多例水库诱发地震的报导。今后，世界各地还将继续修建更多高坝和大库，还将出现更多的水库诱发地震。我国目前在西南和西北正在规划设计或动工兴修许多座大型水库，还考虑在长江三峡和红水河等地修建世界罕见的特大型水库和特高的水坝，为了工程建设经济合理和安全可靠，不仅要科学地评定当地的地震烈度，也必不可少地要对水库诱发地震做出细致的分析和科学的判断。因此，对水库诱发地震的认识剖析和预测预报已经成为紧迫的科学问题摆在地震工作者、工程地质学者和水利工程建设者面前。正确地认识水库诱发地震并且能够在工程建设之前做出合适的预测，将对工程建设和社会经济发展产生巨大的经济效益。同时，研究这种类型的地震活动，将丰富和推动地震科学的发展，是地震科学不可缺少的分支。

我国从60年代初期，在广东省河源县新丰江水库遇到水库诱发地震问题。在人民政府的支持下，广大地学工作者严肃认真地开展了水库地震的监测和分析工作，积累了十分丰富和珍贵的资料。他们的辛勤劳动是我们今天取得一切进展的基础。为了推进水库地震研究的发展，总结归纳近30年来科学家们在水库地震方面的研究成果，从中寻找具有规律性的经验，探索水库诱发地震的机理，以利于未来的生产实践和经济建设，供正在从事这方面工作的有关人士参考，我们编著了本书。如果书中确有某些有助于今后工作的内容，则应归功于从60年代以来，在这个领域中，不畏艰难，开拓前进的前辈，归功于在生产第一线坚守岗位的地震工作者。我们愿意以这本书做为对他们的敬意和礼物。

本书不论震例的解剖，或理论问题的探讨，都侧重介绍中国地震学家的研究成果。新丰江水库地震不仅是世界上震级最大的水库地震之一，也是中国的科学工作者在这个领域中研究时间最久，积累资料最丰富的震例，所以本书比较详细地阐述了新丰江水库地震的详细情况，读者可以从中了解水库地震的某些共同特征，以及中国水库地震的研究程度和基本途径。本书的第一部分全面地介绍了新丰江水库的地质背景、地震序列、地形变特征、震源机制、震源应力场、地震成因和发展趋势，其中包括新丰江水库及邻近地区的地震记录和其他有关实际资料，也有国内许多单位的科学家先后公开和未公开发表的有关新丰江水库地震的论述。与此同时，著者按照自己的认识，对有关材料作了一定的解释和评论。本书的第二部分介绍了中国和世界其他水库地震震例。在丹江口水库（湖北）、参窝水库（辽宁）、柘林水库（江西）、乌江渡水库（贵州）和乌溪江水库（浙江），先后发生5级或更小的地震。这些地区的地震活动都在一定时期与水库水位的变化存在良好的相关性。诱发地震活动较水库蓄水有不同程度的时间滞后。虽然它们发生于地震活动水平不高的地区，可是，水库蓄水

明显改变了库区地震活动的强度。除个别震例外，这些震例几乎都位于中国强烈地震带之外，并且有某些共同的特征。这些水库库区地质不尽相同，既有石灰岩等沉积岩，也有火山岩、侵入岩和变质岩；有的库区附近有活动断层或大型断层通过，而另外一些水库则仅有较小规模断裂分布。这些水库的坝高、库容、水库形状和蓄水过程等水库自身的条件也有差别。通过这些震例的介绍，不仅可以了解到中国水库地震的基本情况和特征，而且还将有助于认识水库地震的形成条件和类型。世界水库地震分布于亚洲、欧洲、非洲、南北美洲和澳洲。它们的特征和形成条件迥然不同。这方面的资料对于研究水库地震具有重要意义。因限于篇幅和避免重复，本书仅选择极少数震例作了概略介绍，其目的在于说明水库地震的共性和多样性、复杂性，并且将为探讨水库地震的成因问题提供基本的素材。本书的第三部分分析探讨了有关水库地震成因的几个问题，诸如导致水库地震的诱发因素、有利于形成水库地震的地质构造条件、水库地震的类型、水库地震的预测预报和水库地震对策等。这些内容都是正在探索的科学课题。本书力求能够粗略地勾划出这些问题的轮廓和症结，并简要地介绍了这方面的最新进展。同时，这部分的内容更多地反映了著者的观点和认识，也包括我们对问题的思考和困惑。在今后的实践中，将逐步证明这些认识哪些是正确的、哪些是部分正确的或全部是错误的。我们深信，关于水库地震的认识必将不断丰富、补充、修改和提高。著者希望，通过本书的出版引起读者对水库地震的兴趣，在水利工程建设中，更加重视这个具有意义的工程地震问题。

本书的撰写工作历经了7年。1981年著者们拟定全书宗旨和章节目录。1982—1983年由丁原章(绪论、第十三——十六章、十八章)、常宝琦(第六、十四、十七、十八章)、肖安予(第一、三、十二、十三和十五章)、潘健雄(第二、十、十五章)、周克森(第八章)、陈益明(第五、七和十一章)、吴景浓(第十五章)、陈俭德、卢沃圻(第九章)和曾宪泽(第四章)等分别编写。以后，撰写工作由于种种原因，一度中辍。1987—1988年由丁原章汇总和统稿，同时对全书的技术思路、内容重点和章节安排重新作了调整，也对各章作了删节和补充。期间，曾数次易稿，两次打印成书，征求意见。本书的第二次征求意见稿曾得到了丁国瑜、马宗晋、徐煜坚、谢毓寿、梅世蓉、夏其发、高士钧、张郢珍、闵子群及其他专家学者的指导和鼓励，还应特别指出，马杏垣教授专为本书作序，卢荣俭研究员为绪论翻译成英文，使本书增添了光彩，谨致谢忱。

本书的编写工作得到陈仁法的协助，杨廉法、沈立英、黄一川、罗世英、许同春等同志都作了可贵的支持。

丁原章

1988年5月

Preface

Seismicities in reservoir areas are bound to follow the impounding reservoir in the world. This kind of earthquakes markedly differs from those activities before impounding in active level, and it is charactered by the difference from general tectonic earthquakes. In a certain period, especially in the early days of impounding, there are clearly corresponding relationships between the seismicities in the reservoir and the level of reservoir and its fluctuation. There are some characteristics for these seismicities in spatial distribution, the change of focal depth, earthquake sequence, focal mechanism, seismic structure and development of seismicities. This kind of earthquake is called the reservoir induced earthquakes (RIE) or, in brief, the reservoir earthquakes.

There is a short history for understanding the reservoir earthquakes. It has elapsed only half century since the RIE, the Marathon earthquake, Greece, was noted in the earliest time. This earthquake of magnitude 4.7 was induced in 1938, but no attention was given at that time. Reservoir induced earthquake was not considered as a scientific problem until the induced earthquake of magnitude 4.6 in Lake Mead, U.S.A. in 1939. At that time, a few scientists suggested that in comparison of the water load on the reservoir with the mass and the strength of the base rock underlaying, the former seem so small, and could be neglected, that no relationship appeared between reservoir and induced earthquake. Some scientists denied the reservoir earthquake, based on the fact that no earthquake occurred in the vicinity of some high dams in the world. Even now some scientists still doubt the existence of RIE. They think that there is only a small probability for the occurrence of these earthquakes. However, undoubted fact is the successive reports that the unprecedented seismicity appeared in a reservoir area or vicinity of dam after filling it, and the seismicity level was obviously altered by the filling. Many facts show not only that filling of reservoir is associated with the seismicity in space, but also the change in water level is related closely to the local seismicity in time. Now we have over 100 examples of RIE believable in the world, in which ten more events occurred in China. The reservoir earthquakes have been verified by many scientists and

accepted by engineers in many countries.

Reservoir earthquake all occur in the vicinity of a water conservancy project. Earthquake damage causes not only direct economic loss, but possibly the serious secondary disaster such as dam destruction,power cut,etc. The study on reservoir induced earthquake is significant in many aspects, including practical significance in economic construction, earthquake resistance, disaster preparedness, and theoretical significance in scientific research. Various task are related to the reservoir induced earthquakes,and put forward problems having to be solved.

1. In the stage of investigation of a hydropower project design,prediction of the occurrence probability of induced earthquakes at the site of the project, location of induced earthquakes and their magnitudes, and effect on a reservoir or a dam should be made as accurate as possible, so that certain criteria for earthquake proof can be both reliable and economic.

2. Once an earthquake or earthquakes occur in a reservoir area after the reservoir is filled, one should decide whether it is an induced earthquake, make an analysis for the seismic tendency, and clarify whether aseismatic measure should be taken. All of the answers depend on the understanding and identification of reservoir earthquakes.

3. Reservoir area, in which reservoir induced earthquakes occurred, will become an appropriate experimental site for the study of earthquake prediction and cause of earthquakes.

4. Investigation of the generating conditions and machanism of reservoir induced earthquake is an optional approach for the study of artificial release of strain energy within a tectonic structure prepairing earthquake, and for the purpose of reducing a strong earthquake to some small ones and controlling the occurrence of disastrous and destructive earthquakes.

Neglect and lack of understanding of reservoir earthquake lead to losses and disasters. For example, earthquake proof was not considered in the desingn of the Koyna Reservoir located in the O-intensity zone in the seismic zoning map of India. After filling, an earthquake of magnitude 6.4 was induced about 3 Km away from the dam. Consequently the whole project was heavily damaged and the power supply interrupted in certain duration, causing the local industry paralysed. Although the magnitude of the induced earthquake was not high, people had to limit the filling of the reservoir to avoid a strong earthquake. Furthermore, strengthening of the dam was need to compensate the neglect of induced earthquake in the design. Consequently,the total investment of the project was increased considerably.If strong earthquakes had been happened after filling of the reservoir, the conse-

quence would have been more serious. More and more events have proved that earthquakes may be induced after filling, and this kind of earthquake will bring about an consequence which can not be neglected for a project and economic development.

It is necessary to emphasize that the local seismic level in many regions where earthquakes occur frequently, has no change since the reservoir was built. On the contrary, in some regions where seismic activity level is not high, but rather strong earthquakes are induced after the establishment of the reservoir. What is the reason that earthquakes are induced in some reservoir areas? It is important substance of researching reservoir earthquake to study and understand clearly the condition of inducing seismicities by reservoir.

Although attention had been paid by someone to the reservoir induced earthquake early in the forties, it was not international academic circles until the sixties, when the Xinfengjiang, the Krimasta, the Kariba and the Koyna reservoir earthquakes of magnitude over 6 occurred and caused serious damage and life loss. In 1969, the Induced Earthquake Expert Group was established by UNESCO. Seminars were held by the Group successively in 1970, 1971 and 1973, exchanging study information on induced earthquakes and analyzing the data of 30 large reservoirs related to the relationgship between reservoir and seismic activity. It is shown in the study that nearly half of the reservoirs were associated with earthquakes after filling, and the frequency and the magnitude of induced earthquakes exceeded those in the past in the local area. Then reservoir earthquake appeared to be a problem discussed in many international conferences. In 1975, the First International Symposium on Induced Earthquakes was held, sponsored by UNESCO and the related Canadian organization, with reservoir induced earthquake as its main theme. In 1976, the Intergovernmental Conference on Evaluation and Matigation of Seismic Risk was also organized by UNESCO, where the induced earthquake phenomena were discussed. Meanwhile the reservoir induced earthquakes of $M_S \geqslant 6$ occurred in China, Africa, Greece and India successively in the sixties. The above-said earthquakes and other events have provided valuable data and clarified the task for the study of reservoir earthquake. In the middle of the sixties, the study on reservoir induced earthquake was supported and supplemented by the evidence of injection-induced earthquakes (M. D. Evans, 1966, J.H.Healy et al., 1968). In the early part of the sixties, some waste water was injected into the base rock in the vicinity of an ordnance factory in Danford, Colorado. In April, 1962, the earthquakes which had never been known were recorded in Danford.

M. D. Evans has made a believable argument that these earthquakes were associated with the injection made by the ordnance factory. Later on, the scientists of geological survey of America and Japanese scientists carried out the study on injection-induced earthquake in Rangely oil field, west of Colorado and Matsudai, Japan respectively, in order to explore the nature of such earthquakes. Injection in Rangely oil field caused an increase of pore pressure in the underground sandstone layer and the pore pressure required for induced earthquake was measured. This prved that advancing of the su critical value of such peak pressure was closely related to seismic activity. These were two respects in the study of reservoir earthquake which were the prominent success in the seventies. Mr. and Mrs. Gough emphasized the effect of elastic deformation caused by reservoir loading, while J.H.Healy et al. (1968) stressed on the effect of pore fluid pressure. Various fields in earth science——seismology, geology, rock mechanics, hydrogeology, have given attention to the study on induced earthquake in some symposiums held in this period, such as those held in London (1973) and in Banff, Canada (1975). In these symposiums, some new concepts were proposed, e.g. stress corrosion (C. Kisslinger, 1975). Following the seventies, more events occurred in the world, profound study on reservoir earthquake was carried on further. In the above study, it was assumed that the induced mechanism was a complicated multi-factor process and a summary was made for the origin conditions of reservoir earthquake. Classification of reservoir earthquakes were studied too. It was considered in all studies that filling of reservoir can induce earthquake, but the induced earthquake is also closely related to the geological tectonic situation. For example, G. Leblanc and F. Anglin (1975) suggested that the Manicouagan No. 3 reservoir earthquake, Canada, was highly associated with the base rock of high permeability under the reservoir and the water permeating along the weak structural plane. However, there were also the cases with no rela io ship with tectonic rupture, e. g. the reservoir earthquake occurred in the Oued Fodda, Algeria where no tectonic rupture was found in the reservoir area. It was explained that the earthquake was induced by the expansion of the underlying unhydrated gypsum layer filled with the permeated water. It has suggested also by some others that it was induced by the collapse of the deep salt layer under the reservoir base, dissolved by the reservoir water. Furthermore, reservoir earthquake, such as the Oroville earthquke(C.G.Bufe et al.1976; T.R.Toppozada et al.1982), the Nurek earthquake(D.W.Simpson and S.Kh. Negonatullaev, 1981; C. M. Keith et al, 1982) , the Monticello earthquake (P.Talwani, 1979) and the Aswan (R.M.Kebeasy et al, 1981; D.W.Simpson

et al, 1982) had been further analyzed.

The study on reservoir earthquake in China started early in the sixties, following the field investigation for the Xinfengjiang reservoir earthquake. Construction of the dam began in July, 1958. In the design of the dam, the basic intensity of the site area was evaluated as VI, based on a few available data. Therefore, no aseismatic measure was taken. The seismic activity increased obviously shortly after the reservoir was filled in October, 1959. In 1960, perceptible earthquakes occurred frequently, among which there was a destructive earthquake of intensity VI near the dam. scientists and engineers had been organized by Academia Sinica to investigate the seismic activity. The first seismic station was established downstream of Xinfengjiang dam in Oct. 1960. At that time, It was not clear why the seismic activity was increasing obviously and whether the filling of the reservoir affected the seismic activity directly. But, for the safty and importance of the dam, the authority concerned had decided to strengthen the dam on one hand (based on intensity Ⅶ) and carry out study on the cause of increase of seismic activity, tendency of earthquakes, seismic risk at the site and the relationship between seismic activity and geological structure on the other. In Oct. 1961, the first symposium on Xinfengjiang dam held in Guangzhou where problems on geological structure, engineering geology, seismology, Geomorphology and hydraulic engineering of the reservoir were discussed. There were different opinions about whether the increase in seismic activity was related to the filling of reservoir or not. Some considered that seismic activity had no relation to the filling, and others suggested there would be no earthquakes of intensity above VI to occur in the future, as no such earthquakes occurred in the past. However, the sudden increase in seismicity had motivated the Chinese scientists and the study was thus carried on progressively. Geological map of the reservoir area was being plotted and study of geological structure conducted. On the other hand, seismic station network was developed, strong motion instruments had been located on the dam, triangular survey network and precise levelling network distributed in the valley district. The locations were selected for the measurement of ground stress and fault displacement. In addition, model tests of the dam and rock mechanical tests were carried out too. In March, 1965, the 2nd Xinfengjiang Reservoir Symposium was held in Guangzhou where the development and study of reservoir earthquake since 1962 was reported. It was considered at the symposium that seismic activity in the area will approach a relatively low level, but it would take a few decades to reach the calmness, me a nwhile fluctuation would appear conti-

nuously. These points of view have been verified by the consequent events.But different opinions existed as to the cause of reservoir earthquake.Some emphasised that reservoir loading plays an important role while some considered that reservoir earthquake can only be induced in the seismic area where past earthquakes frequently occurred. The former assumed that reservoir itself is the main cause of earthquake, but the latter insisted that geological structure was the necessary condition for induced earthquakes. A paper(the Xinfengjiang Reservoir Earthquake and Its Effect on the Dam by C.G.Shen et al.)written by the scientists who had conducted their study on the Xinfengjiang reservoir earthquake was presented in the 10th International Large Dam Conference,Spain.It was clearly indicated in the paper that the filling of the reservoir induced the earthquakes.Also, analysis for the origin conditions of induced earthquakes was made in the paper.It was assumed that the weak rupture stripe within the rock body played an important role in the reservoir circulation and the induced earthquake. Later, advanced study and discussion on the origin conditions and the law concerning the development of reservoir earthquakes have been progressively carried out by J.Ma(1975), M.Y.Wang (1975) , Y.Z.Ding(1978,1980,1982) et al. New concepts on the tectonic stress field of the reservoir earthquake origin, types of main shock and after shocks and their causes, characteristics of reservoir earthquake were proposed respectively.Study of the Xinfengjiang reservoir earthquake has been carried out for nearly 30 years in China. The main features of the study are as follows:

1. The study is closely related to the seismic risk analysis of the dam. Strengthening of the dam based on intensity Ⅶ at the first stage and intensity Ⅸ at the second stage was on the basis of this study. Therefore, from the sixties onward, the study on reservoir earthquakes in China has been closely related to practice and has indeed provided a necessary basis for economic construction.

2. As far as methodology is concerned,a conprehensive study was made by multiple disciplines. From the beginning of the study, a combination of seismology, geology, rock mechanics, hydrologic geology, simulation test, measurement of earth deformation and geophysical survey etc.was emphasized.

3. As far as the research task is concerned,the study has been carried in the way of prediction of reservoir earthquakes.In recent years, Chinese scientists have summarized the law of reservoir earthquake occurrences and suggested a tendency of the earthquakes for different construction periods of the dam. They have been making a great effort in providing an

use for reference to other reservoirs being built or to be built.

The Xinfengjiang Reservoir provides an excellent site for the study of reservoir earthquakes in China. The study also provides a basis for the study of other reservoir earthquakes and sets up a research team for reservoir earthquakes. In the seventies and eighties, Li Ping et al.(1972) and Gao Shijun et al. (1980) at Danjiangkou Reservoir, Hu Yuliang (1972, 1985) at Wujiangdu Reservoir and wuxijiang Reservoir, Ding Yuanzhang et al. (1983) at Zhelin Reservoir studied the reservoir earthquakes in detail respectively. Since the eighties, the study on the origin conditions and classification of reservoir earthquakes was performed by Xia Qifa et al.(1984), Li Zuwu (1984) and Li Qitong (1986) etc. to various extent. With the development of hydraulic resource and construction in China, a preliminary study has been made of the feasibility of reservoir earthquake prediction for the design and construction of reservoirs. Chang Baoqi et al. (1986) tried to predict reservoir earthquake quantatively in the Longtan Reservoir, Guangxi province by means of probabilistic method and comprehensive fuzzy evaluation. By the effort of Chinese scientists in recent years, an approach to the study of reservoir earthquakes with Chinese features has been created.

In the last twenty years, the observation and study of reservoir earthquakes has made a significant progress either at home or abroad. The research work concerned has developed from independent study and observation of an individual reservoir to a comprehensive observation and comparitive analysis of a series of large reservoirs; the observation system from individual seismic stations to a seismic station network with radio or wire transmission and a quick data processing by computers; the aspects of study from field observation and analysis to a comprehensive scientific research by multiple disciplines including field measurement, experimental study and physical and mathematical simulation. At the beginning, study was carried out only after the induced earthquake occurred. But now, study has been extended to all high dams ($\geqslant$100m) and reservoirs of large capacity ($\geqslant 10\times10^9 m^3$) . A relatively systematic observation and study should be performed before the design or construction of these dams or reservoirs, so that an evaluation of the risk of induced earthquakes can be made at the site. Study on induced earthquakes due to the filling of oil field and the injection of water into deep well and the effect of water permeability is an important approach to explore the mystery of the reservoir earthquakes.

Of course, the study on the reservoir earthquakes in China or abroad