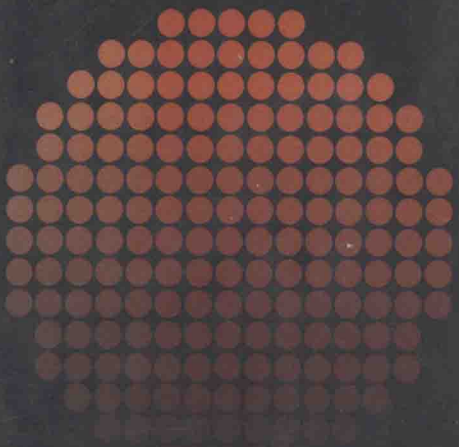
EARTHQUAKE FORECASTING AND WARNING

Tsuneji Rikitake

Developments in Earth and Planetary Sciences
03



Center for Academic Publications Japan
D. Reidel Publishing Company

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Center for Academic Publications Japan/Tokyo
D. Reidel Publishing Company/Dordrecht · Boston · London

Library of Congress Cataloging in Publication Data

DATA APPEARS ON SEPARATE CARD

ISBN 90-277-1218-2

Published by Center for Academic Publications Japan, Tokyo, in co-publication with D. Reidel Publishing Company, P. O. Box 17, 3300 AA Dordrecht.

Sold and distributed in Japan, China, Korea, Taiwan, Indonesia, Cambodia, Laos, Malaysia, Philippines, Thailand, Vietnam, Burma, Pakistan, India, Bangla Desh, Sri Lanka by Center for Academic Publications Japan, 4-16, Yayoi 2-chome, Bunkyo-ku, Tokyo 113, Japan.

Sold and distributed in the U.S.A. and Canada by Kluwer Boston Inc., 190 Old Derby Street, Hingham, MA 02043, U.S.A.

Sold and distributed in all other countries by Kluwer Academic Publishers Group, P. O. Box 322, 3300 AH Dordrecht, Holland.

Printed in Japan

Damage to the library building of the Tangshan Mining College by the 1976 Tangshan earthquake of magnitude 7.8 (photo by Rikitake, 1981).

Damage to the steam locomotive engine factory by the 1976 Tangshan earthquake of magnitude 7.8 (photo by Rikitake, 1981).

PREFACE

Studies related to the earth and planets along with their surroundings are of great concern for modern scientists. Global geodynamics as represented by plate tectonics has now become one of the most powerful tools by which we can study the causes of earthquakes, volcanic eruptions, mountain formation and the like. Various missions sent out to space, manned or unmanned, brought out geoscientific features of the moon, Mars, Venus and other planets. Earthquake prediction that was the business of astrologers and fortune-tellers some twenty years ago, has now grown up to be an important science. A number of destructive earthquakes were successfully forecast in the People's Republic of China.

In the light of the above-mentioned and other accomplishments in geosciences, we feel that it is a good thing to publish a series of monographs which review selected topics of earth and planetary sciences. We are of course well aware of the fact that similar monographs have been and will be published from overseas publishers. The series, which we plan to publish, will therefore stress Japanese work. But we hope that the series will also include review articles by distinguished overseas authors.

The series, which is named the "Developments in Earth and Planetary Sciences" will be published by the Center for Academic Publications Japan and the D. Reidel Publishing Company. It is my great pleasure to work as the Editor of the series. I should like to have comments on what subjects we shall choose in future publications. I shall be greatly obliged if anyone would suggest suitable subjects and potential authors for the series to me.

Tsuneji Rikitake
Editor

PREFACE TO VOLUME 3 AND INTRODUCTORY REMARKS

A Symposium on Earthquake Prediction was held at the Headquarters of the United Nations Educational, Scientific, and Cultural Organization (UNESCO) in Paris on April 2–6, 1979. Some 240 scientists participated in the symposium from 40 different countries. The most outstanding and important feature of the symposium consisted of researchers working in the fields of natural and social sciences sharing the discussion. Even administrators responsible for disaster prevention and civil defense and representatives of insurance companies attended the sessions.

It appears to the author that the fact that such an international symposium tackling earthquake forecasting and warning from both sides of natural and social sciences was successfully held indicates that earthquake prediction is now becoming a matter of actuality. It is true that technology of earthquake prediction is still in a developing stage. But social demands for practicable prediction of destructive earthquakes are so strong that every effort should be concentrated toward actual prediction even if the probability of false prediction is not inconsiderable.

The 1975 Haicheng earthquake of magnitude (M) 7.3 in Liaoning Province, China was successfully predicted. In this case, long-, medium-, and short-term predictions were issued along with an imminent prediction several hours prior to the main shock. This was the first prediction of destructive earthquake in history. Three more

earthquakes larger than $M=7$ were predicted in China in 1976 although no imminent prediction was issued for the 1976 Tangshan earthquake ($M=7.8$) which killed a few hundred thousand people.

Earthquake prediction programs that started in the 1960's in China, Japan, the U.S.A., and the U.S.S.R. made such remarkable progress that many an earthquake precursor has been identified through intensive geophysical and geochemical observations. Particularly, the development of earthquake prediction research in recent years has been amazingly rapid, so that considerable data pertinent to earthquake prediction are now available.

The author wrote a book entitled "Earthquake Prediction" which was published in 1976 (RIKITAKE, 1976a). This work covered then-available aspects of earthquake prediction. As was anticipated even at that time, the progress of earthquake prediction study has so escalated that substantial new study material can be added to that original work. For instance, 282 examples of earthquake precursor were analysed in that book. According to the author's survey, the number of reported precursors has increased so rapidly since 1976 that 391 geophysical and geochemical precursors were called to his attention by the beginning of 1978.

Extensive networks of seismographs, tiltmeters, strainmeters, tide-gauges, gravimeters, magnetometers, resistivity variometers, radon content monitors, and the like, have been set up in recent years over earthquake-threatened areas in China, Japan, the U.S.A., and the U.S.S.R. It may be said, therefore, that a dramatic intensification of observation systems aimed at actual earthquake prediction has been completed, although further intensification is certainly necessary.

Another aspect of earthquake prediction and warning as advanced in the last 5 years or so is the study of public reaction against a warning of a highly destructive earthquake. It has been pointed out by pilot studies that an untimely issue of earthquake warning could sometimes result in severe social and economic damage which may exceed that caused by the earthquake itself. It is now recognized that the socioeconomic aspects of earthquake prediction and warning should be extensively studied prior to an actual warning.

Special legislations for mitigating earthquake hazards were made in the U.S.A. and Japan respectively in 1977 and 1978. The Japanese

law called the "Large-scale Earthquake Countermeasures Act" is unique in the fact that countermeasures against earthquake hazards will be taken on the basis of long- and short-term earthquake prediction information. It may be that the feasibility of achieving actual earthquake prediction has more or less become a nation-wide consensus, at least in Japan, although earthquake prediction is still in a developing stage.

In the light of recent achievements as mentioned above, the author considered it prudent to publish a book that summarizes new developments of earthquake prediction and warning. Actually, a book in Japanese for that purpose has already been written by him and was published by the Center for Academic Publications Japan / Japan Scientific Societies Press in 1979. The author holds the opinion, however, that such a book should also be published in an internationally accessible language such as English, otherwise the book is of little value internationally.

Although Japan is one of the leading countries putting emphasis on earthquake prediction, most data compiled in Japan has been published in Japanese journals in the Japanese language difficult to read for overseas colleagues. Such data, of great importance for earthquake prediction study, should be presented to overseas researchers in an accessible form.

For those reasons the author undertakes anew the writing of the present volume. To tell the truth, however, this book is not a mere translation of the book in Japanese that has already been published. Further advances in the study of earthquake prediction and warning took place even during the relatively short period between the time when the Japanese edition was published and the present. It is planned to make the present book as up-to-date as possible by covering all these new findings.

The author will try in this work not to repeat that written in the previous publication "Earthquake Prediction" except for minimum overlaps that are absolutely necessary for reasoning, so that those who are interested in overall aspects of earthquake prediction are kindly asked to refer to both books.

It was the author's privilege to visit China and see some of the Chinese efforts toward earthquake prediction in September, 1978. He

and his delegation were privileged to visit the Songpan-Pingwu area, the epicentral area of the 1976 large earthquakes ($M = 7.2, 6.7, 7.2$), in Sichuan Province, where they were the first foreigners to enter that area. Chinese experiences in relation to forerunners of an earthquake are sometimes so fantastic that it is really hard to grasp the facts. Nevertheless it should be borne in mind that the Chinese succeeded in issuing imminent earthquake predictions 4 times among 5 destructive earthquakes during 1975–76. It seems that macroscopic phenomena such as anomalous animal behavior, fire-ball appearance and the like are sometimes observed very clearly in China forerunning a large earthquake. Although the author does not presume his complete understanding of the Chinese way of earthquake prediction even after two more visits to China in 1980 and 1981, he will attempt in this book to introduce the Chinese approach to earthquake prediction to occidental colleagues as accurately as possible. That the Japanese can read many Chinese characters is an advantage for such a purpose.

This volume consists of two parts. Part I is devoted to summarizing the natural science side of earthquake prediction based on the most recent information. Meanwhile, social consequences of earthquake prediction and warning along with relevant legislations will be dealt with in Part II. Although a geophysicist, the author attempts to cover the topics in Part II, because those subjects are vitally important even to those working on the natural science side of earthquake prediction. It will be the author's pleasure if a sociologist would undertake to further expand his findings.

Part I consists of 7 chapters. In Chapter 1, the author will attempt to summarize the current state of earthquake prediction programs in Japan, the U.S.A., the U.S.S.R., and the People's Republic of China. Dramatic intensification of the Japanese program in recent years can well be recognized by comparing the material contained in Chapter 1 to that stated concerning the Japanese program in the author's previous book. The system of deep-well seismic observation around the Tokyo area, as well as that of sea bottom seismographs as extended off the Pacific coast in the Tokai (literally means East Sea) area, an area between Tokyo and Nagoya under menace of a great earthquake, are quite unique among earthquake prediction observations in the world. Being extended more

than 100 km off the coast and telemetered to the Japan Meteorological Agency (JMA) in Tokyo on real-time basis, the latter system serves for short-term and imminent prediction of the feared Tokai earthquake, the magnitude of which is estimated as 8 or so, should it occur.

An extensive network of observation by volume strainmeters, tiltmeters, seismographs, tide-gauges, underground-water monitors, and the like have been spread all over the Tokai area and most of them are telemetered to JMA on an on-line real-time basis.

A nationwide geodetic survey has been intensified in recent years. As to microearthquake observations, extensive telementering systems are now available. Chapter 1 includes a description of the above developments in the Japanese program in detail along with its budgetary developments.

The U.S. national project on earthquake prediction launched in 1973 as a part of the Earthquake Hazards Reduction Program (EHRP) was mentioned in the previous text. The budget for EHRP increased discontinuously in 1978.

A remarkable installation is that of the U.S. Geological Survey (USGS) Californian system of microearthquake observation in cooperation with the California Institute of Technology (CIT), the number of seismograph stations exceeding 500. Observations of various disciplines are also provided along the San Andreas fault. Special attention has been paid to the anomalous land uplift in southern California since 1976.

All these U.S. efforts will be reviewed in Chapter 1 on the basis of published information as well as the author's material gathered from American colleagues.

Chapter 1 also covers the advances of the U.S.S.R. program on earthquake prediction although only relatively limited information has reached the author perhaps because of linguistic difficulty.

In contrast to the very brief description of the Chinese program on earthquake prediction in the previous text, a fairly detailed report of the Chinese program is now contained in Chapter 1. A number of American, Canadian, and Japanese seismological delegations have visited China in recent years. In return, a few Chinese missions on seismology visited these countries. It was therefore possible to become

aware of the Chinese program on earthquake prediction through the reports of these exchange programs. It was most fortunate for the author that he and his delegation could visit Peking (Beijing) and its surroundings, Shenyang-Haicheng-Yingkou area in Liaoning Province and Chengdu and Songpan-Pingwu area in Sichuan Province in 1978. The author enjoyed two more visits to China in 1980 and 1981.

That the Chinese constructed an incredibly large number of observation stations with countless workers, that observations by amateurs play an important role on earthquake prediction, and that macroscopic precursors such as anomalous animal behavior (which can be observed by the eye and ear, often observed very clearly in China) will be described in Chapter 1 in relation to the Chinese program on earthquake prediction. It is really interesting that ways and means for actualization of earthquake prediction, sometimes difficult to understand on the basis of western logic, have been adopted with success in China.

Chapters 2 and 3 will be reserved for analysis of earthquake records in history and monitoring of crustal strain by repeating geodetic surveys. They are useful for extremely long-range earthquake forecasting. The importance of historic documentation of earthquakes covering about 3,000 and 2,000 years respectively in China and Japan in relation to monitoring future seismicity has long been recognized although much of existing documentation was only qualitative. In Chapter 2, however, a quantitative study, namely examples of probability estimate for recurrence of great earthquakes at subduction zones, will be demonstrated only from analysis of historical records. Migration tendency of seismicity will also be presented including occurrences of large Sichuan and Yunnan earthquakes in China alternating one with the other. Recent knowledge about seismic gaps will also be one of the topics of this chapter.

Estimation of crustal strain accumulation and statistics of ultimate crustal strain as presented in the previous text have been improved as will be seen in Chapter 3. Discussion is focused at the Tokai area in Central Japan where we have every reason to expect a great earthquake to occur sooner or later.

What will be presented in Chapters 2 and 3 are only concerned

with extremely long-range forecasting of earthquake occurrence or, in other words, it is only appropriate to call them the "regionalization." However, much more concrete symptoms forerunning an earthquake must be detected in order to make an actual earthquake prediction. Chapter 4 will be devoted to presenting many recently-reported precursory effects which may foretell occurrence of an earthquake. It is really remarkable that the number of reports on earthquake precursors has increased so enormously in recent years perhaps because of the completion of observation networks under earthquake prediction programs in each country.

It seems likely that there are precursors of various disciplines, i.e. land deformation, change in sea-level, change in tilting of the ground and strain and stress in the earth's crust, foreshock, anomalous seismic activity prior to the main shock, seismic gap of the 2nd kind (decrease in the activity of small earthquakes prior to the main shock), *b* value (a parameter representing the ratio of number of occurrence of relatively large shocks to that of relatively small shocks), change in source mechanism, hypocentral migration, change in seismic wave velocities, change in earth-tidal amplitude, change in the geomagnetic field intensity, change in the amplitude of short-period geomagnetic variations originating primarily from outside the earth, change in earth-currents, change in earth resistivity, change in gravity, change in undergound water level and chemical content especially that in radon content and so on. It will be planned in Chapter 4 to make the characteristics of these precursors clear on the basis of the now-available data examples amounting to 391 in number.

It is interesting to note that many macroscopic precursors, as exampled by Chinese scientists have been disclosed in recent years on the occasions of strong earthquakes in various countries. They are just observed by the eye, ear, and nose without making use of more sophisticated instruments. The author will try to summarize in Chapter 4 what he learned about anomalous animal behavior, fire-ball appearance, well-water change, and the like forerunning an earthquake as gathered from Chinese colleagues during his visit to China. A few studies on anomalous animal behavior in the U.S.A. as well as in Japan prior to a large earthquake will also be included in

this chapter.

Strategies of earthquake prediction currently under consideration in Japan, China, and possibly in other countries will be the subject of Chapter 5. First of all, the rating of earthquake-threatened areas by the Coordinating Committee for Earthquake Prediction (CCEP) will be mentioned. The CCEP, the headquarters of earthquake prediction in Japan, is working hard on detecting premonitory effects over the areas of intensified observation. Starting from an extremely long-term prediction as will be discussed in Chapters 2 and 3, earthquake percursors are to be detected by intensified observations. The occurrence time of an earthquake will then be estimated on the basis of the characteristics of precursors observed. In the case of an actual prediction, the importance of overall judgment based on many precursors will be stressed.

In order to achieve earthquake prediction by means of the strategy as presented in Chapter 5, a system of earthquake prediction must be developed. In Chapter 6 will be described the earthquake prediction systems in Japan, the U.S.A., and China in fair detail. Special mention will be made of the Prediction Council for the Tokai area, Japan, which is under menace of a great earthquake. The Council has been officially called the Prediction Council for the Area under Intensified Measures against Earthquake Disaster as from August 7, 1979 in association with the designation of the Tokai and neighboring areas to the Area under Intensified Measures against Earthquake Disaster under the Large-scale Earthquake Countermeasures Act enacted in 1978 (RIKITAKE, 1979c).

In Chapter 7, the author will attempt to present a comparative study of program, budget, strategy, system, legislation, and the like relevant to earthquake prediction in Japan, the U.S.A., China, and the U.S.S.R. Such a study will be useful for gathering information about the efforts toward earthquake prediction in each country.

Part II, consists of 6 chapters, and will manifest various problems related to conversion of earthquake prediction information into an earthquake warning.

In Chapter 8, case histories of earthquake warning in relation to the Matsushiro, Haicheng, Tangshan, Songpan-Pingwu, and Izu-Oshima Kinkai earthquakes will be presented. It is the author's belief

that these examples are of prime importance to provide the basis for studying the various problems concerned.

Possible classification of earthquake prediction information will be discussed in Chapter 9. The author's idea that the prediction information should be classified according to the time-window of possible earthquake occurrence and the reliability of information will be presented in this chapter.

What form would an earthquake warning take? Except for Chinese instances, no actual issuance of earthquake warning of a great earthquake has been experienced, especially in capitalistic countries. In Chapter 10, possible forms of earthquake warning will be discussed. Special mention will be made of the "earthquake warnings statement" to be issued by the Japanese Prime Minister based on the Large-scale Earthquake Countermeasures Act in case an imminent prediction of a large-scale earthquake is made by the Prediction Council.

One of the difficult problems of earthquake warning is to communicate correct information to the public at large. What happened in the case of Izu-Oshima Kinkai earthquake ($M=7.0$, 1978) in relation to the release of prediction information and aftershock information will be reported in Chapter 11. As demonstrated in this example, the information could be so distorted during its propagation that many people would tend to overreact against the deformed information.

Reaction of the public against an earthquake warning varies from country to country depending upon national traits, economic conditions, and so on. The point that a warning should be issued after knowing possible reaction in detail will be emphasized in Chapter 12. A few examples of such reaction will be covered by the chapter.

Finally, legislations relevant to earthquake prediction and warning will be referred to in Chapter 13. The main topics will be the Large-scale Earthquake Countermeasures Act in Japan and the Earthquake Hazards Reduction Act of 1977 in the U.S.A. Both laws will be cited in the Appendices.

The publication of this book is planned as one of the volumes of the monograph series called "Developments in Earth and Planetary Sciences (DEPS)" published by the Center for Academic Publications

Japan/D. Reidel Publishing Company. Judging from the recent development of earthquake prediction along with the social concern with earthquake warning, the author, who is the General Editor of DEPS, believes that the book is timely. In the course of preparing the manuscripts, the author was assisted by Mr. K. Oshida of the Center for Academic Publications Japan. Miss M. Omi also helped the author through the typing and drawing work. The author is grateful to them. A part of the translating and publishing cost is covered by the grant given to the author by the Ministry of Education, Science, and Culture of Japan for which the author expresses his sincere thanks.

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