Edited by
GIULIANO F. PANZA
VLADIMIR G. KOSSOBOKOV
EFRAIM LAOR
BENEDETTO DE VIVO

EARTHQUAKES AND SUSTAINABLE INFRASTRUCTURE

Neodeterministic (NDSHA) Approach Guarantees Prevention Rather Than Cure

ELSEVIER

EARTHQUAKES AND SUSTAINABLE INFRASTRUCTURE

NEODETERMINISTIC (NDSHA) APPROACH GUARANTEES PREVENTION RATHER THAN CURE

EARTHQUAKES AND SUSTAINABLE INFRASTRUCTURE

NEODETERMINISTIC (NDSHA) APPROACH GUARANTEES PREVENTION RATHER THAN CURE

Edited by

Giuliano F. Panza
Vladimir G. Kossobokov
Efraim Laor
Benedetto De Vivo

ELSEVIER

Elsevier
Radarweg 29, PO Box 211, 1000 AE Amsterdam, Netherlands
The Boulevard, Langford Lane, Kidlington, Oxford OX5 1GB, United Kingdom
50 Hampshire Street, 5th Floor, Cambridge, MA 02139, United States

Library of Congress Cataloging-in-Publication Data
A catalog record for this book is available from the Library of Congress

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library

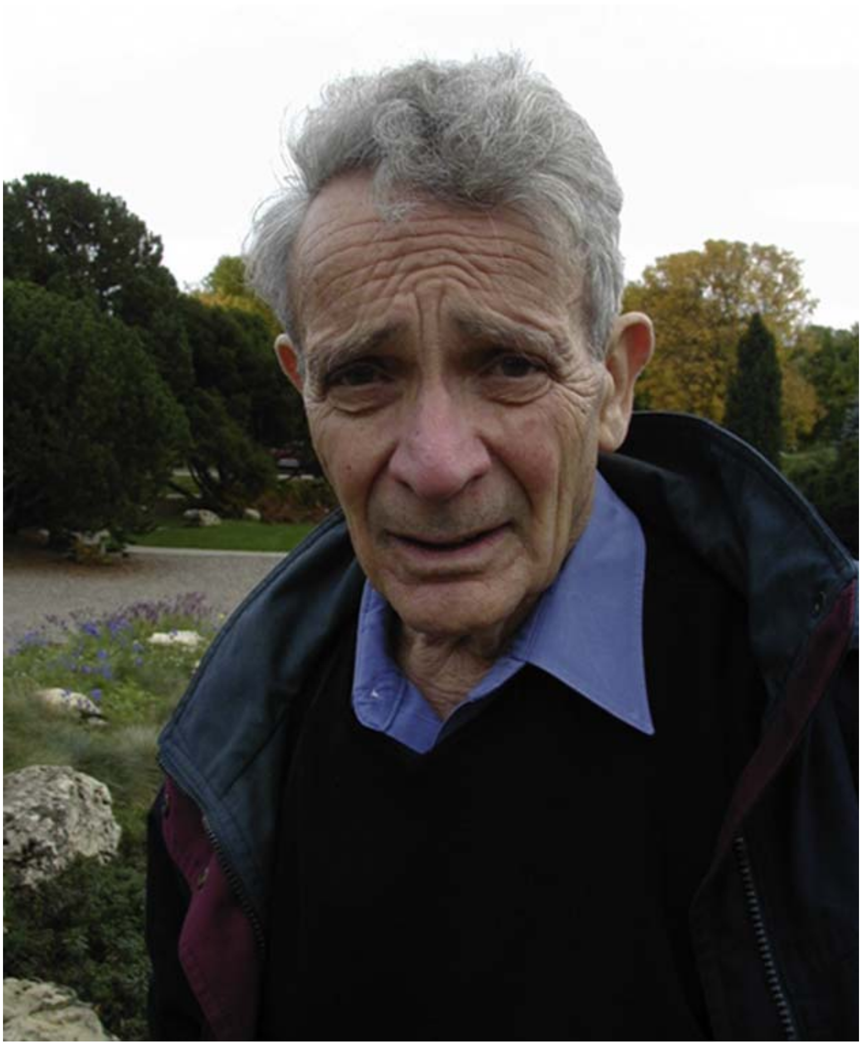
ISBN: 978-0-12-823503-4

For information on all Elsevier publications visit our website at
https://www.elsevier.com/books-and-journals

Publisher: Candice Janco
Acquisitions Editor: Amy Shapiro
Editorial Project Manager: Aleksandra Packowska
Production Project Manager: Debasish Ghosh
Cover Designer: Matthew Limbert

Typeset by TNQ Technologies

In memory and to the centenary of Vladimir I. Keilis-Borok



Vladimir Isaakovich Keilis-Borok (31.07.1921—19.10.2013)

Contents

Contributors

Tahmeed M. Al-Hussaini Department of Civil Engineering, Bangladesh University of Engineering & Technology, Dhaka, Bangladesh

Giorgio Altin Ordine degli Ingegneri della Provincia di Trieste, Trieste, Italy

Bogdan Felix Apostol National Institute for Earth Physics, Ilfov, Romania

Seth N. Carpenter Kentucky Geological Survey, University of Kentucky, Lexington, KY, United States

Sudipta Chakraborty Department of Civil Engineering, Bangladesh University of Engineering & Technology, Dhaka, Bangladesh

Ishika N. Chowdhury BUET-JIDPUS, Bangladesh University of Engineering & Technology, Dhaka, Bangladesh

Gian Paolo Cimellaro Department of Structural, Geotechnical and Building Engineering, Politecnico di Torino, Torino, Italy

Carmen Ortanza Cioflan National Institute for Earth Physics, Ilfov, Romania

Maria Rosaria Costanzo Department of Earth Science, Environment and Georesources (DiSTAR), University Napoli Federico II, Napoli, Italy

Mattia Crespi Geodesy and Geomatics Division, DICEA, Sapienza University of Rome, Rome, Italy

Melissa De Iuliis Department of Structural, Geotechnical and Building Engineering, Politecnico di Torino, Torino, Italy

Benedetto De Vivo Department of Geosciences, Virginia Tech, Blacksburg, VA, United States; Pegaso On-line University, Napoli, Italy; Nanjing University, Nanjing, Jiangsu, China; Hubei Polytechnic University, Huangshi, Hubei, China

Zhifeng Ding Institute of Geophysics, China Earthquake Administration, Beijing, China; Key Laboratory of Earthquake Source Physics, China Earthquake Administration, Beijing, China

Elena Dumova-Jovanoska Ss. Cyril and Methodius University, Faculty of Civil Engineering, Skopje, Republic of North Macedonia

Mohamed N. Elgabry National Research Institute of Astronomy and Geophysics (NRIAG), Helwan, Cairo, Egypt

Lihua Fang Institute of Geophysics, China Earthquake Administration, Beijing, China; Key Laboratory of Earthquake Source Physics, China Earthquake Administration, Beijing, China

Hasan al Faysal Department of Civil Engineering, Bangladesh University of Engineering & Technology, Dhaka, Bangladesh

Shanghua Gao Institute of Earthquake Forecasting, China Earthquake Administration, Beijing, China

Mariano García-Fernández CSIC — Museo Nacional de Ciencias Naturales, Madrid, Spain

Alexander Gorshkov Institute of Earthquake Prediction Theory and Mathematical Geophysics, Russian Academy of Sciences, Moscow, Russia

Hany M. Hassan National Research Institute of Astronomy and Geophysics (NRIAG), Helwan, Cairo, Egypt

Hesham Hussein National Research Institute of Astronomy and Geophysics (NRIAG), Helwan, Cairo, Egypt

Maurizio Indirli ENEA, Italian National Agency for New Technologies, Energy and

Sustainable Economic Development, Bologna, Italy

Irwandi Irwandi Department of Physics, Universitas Syiah Kuala, Banda Aceh, Indonesia; STEM Research Center (STEM.id), Universitas Syiah Kuala

Junbo Jia Aker Solutions, Sandslimarka, Sandsli, Norway

Changsheng Jiang Institute of Geophysics, China Earthquake Administration, Beijing, China

María-José Jiménez CSIC – Museo Nacional de Ciencias Naturales, Madrid, Spain

Jens-Uwe Klügel International Seismic Safety Organization, ISSO, Arsita, Italy; NPP Goesgen, Goesgen, Switzerland

Vladimir Kossobokov Institute of Earthquake Prediction Theory and Mathematical Geophysics, Russian Academy of Sciences, Moscow, Russia; International Seismic Safety Organization, ISSO, Arsita, Italy

Mihaela Kouteva-Guentcheva National Earthquake Engineering Center – University of Architecture, Civil Engineering and Geodesy (NEEC-UACEG), Sofia, Bulgaria

Efraim Laor National Research Institute for Disaster Reduction, Holon Institute of Technology, HIT, Holon, Israel

Andrea Magrin National Institute of Oceanography and Applied Geophysics – OGS, Trieste, Italy

Elena Florinela Manea National Institute for Earth Physics, Ilfov, Romania

Sebastiano Marasco Department of Structural, Geotechnical and Building Engineering, Politecnico di Torino, Torino, Italy

Sokol Marku Marine Geology, Albanian Geological Survey, Tirana, Albania

Kristina Milkova Ss. Cyril and Methodius University, Faculty of Civil Engineering, Skopje, Republic of North Macedonia

Lalliana Mualchin California Department of Transportation (Caltrans), Placerville, CA, United States; International Seismic Safety Organization, ISSO, Arsita, Italy

Concettina Nunziata Department of Earth Science, Environment and Georesources (DiSTAR), University Napoli Federico II, Napoli, Italy

Rapo Ormeni Department of Seismology, Institute of Geosciences, Waters and Environment, Tirana, Albania

Giuliano F. Panza Accademia Nazionale dei Lincei, Rome, Italy; Institute of Geophysics, China Earthquake Administration, Beijing, China; Accademia Nazionale delle Scienze detta dei XL, Rome, Italy; International Seismic Safety Organization, ISSO, Arsita, Italy; Beijing University of Civil Engineering and Architecture, Beijing, China

Imtiyaz A. Parvez CSIR Fourth Paradigm Institute (formerly CSIR C-MMACS), NAL Belur Campus, Bangalore, Karnataka, India

Ivanka Paskaleva EPU, Pernik, Bulgaria

Antonella Peresan International Seismic Safety Organization, ISSO, Arsita, Italy; National Institute of Oceanography and Experimental Geophysics, OGS, Seismological Research Center, Udine, Italy

Habib Rahimi Department of Seismology, Institute of Geophysics, University of Tehran, Tehran, Iran

Mehdi Rastgoo Department of Seismology, Institute of Geophysics, University of Tehran, Tehran, Iran

Giuseppe Rolandi University Napoli Federico II, Napoli, Italy

Fabio Romanelli Department of Mathematics and Geosciences, University of Trieste, Trieste, Italy; Institute of Earthquake Forecasting, China Earthquake Administration, Beijing, China

Leontina Romashkova Institute of Earthquake Prediction Theory and Mathematical Geophysics, Russian Academy of Sciences, Moscow, Russian Federation

Paolo Rugarli Castalia Srl, Milan, Italy

Farhana Sarwar Federal Government Girls Degree College Quetta Cantt, FGEI(C/G), Rawalpindi, Balochistan, Pakistan

Alexander Soloviev Institute of Earthquake Prediction Theory and Mathematical Geophysics, Russian Academy of Sciences, Moscow, Russian Federation

Franco Vaccari Department of Mathematics and Geosciences, University of Trieste, Trieste, Italy

Zhenming Wang Kentucky Geological Survey, University of Kentucky, Lexington, KY, United States

Edward W. Woolery Department of Earth and Environmental Sciences, University of Kentucky, Lexington, KY, United States

Zhongliang Wu Institute of Earthquake Forecasting, China Earthquake Administration, Beijing, China

Yan Zhang Institute of Geophysics, China Earthquake Administration, Beijing, China

Preface

> If you are right and you know it, speak your mind. Speak your mind even if you are a minority of one. The truth is still the truth. ***Mohandas Gandhi***

The book "*Earthquakes and Sustainable Infrastructure: Neo-Deterministic (NDSHA) Approach Guarantees Prevention Rather Than Cure*" aims to communicate in one volume the "state-of-the-art" scientific knowledge on earthquakes and related seismic risks. Earthquakes occur in a seemingly random way and in some cases it is possible to trace seismicity back to the concept of deterministic chaos. Therefore, seismicity, apparently, can be explained by a deterministic mechanism that arises as a result of various convection movements in the Earth's mantle, expressed in the modern movement of lithospheric plates fueled by tidal forces. The polarized plate tectonics and the complex nature of seismic phenomena highlight the need to avoid the use of overly simplistic models, particularly for the assessment of the risks associated with earthquakes. In a perspective of prevention, coherent and compatible with the most advanced theories, it is essential that at least the infrastructure installations and public structures are designed so as to resist (or sustain) future strong earthquakes and continue to operate in their original capacity. An earthquake compatible with the seismogenic characteristics of a certain area, even if sporadic and therefore labeled as "unlikely," can occur at any time.

When an earthquake occurs with a given magnitude M, the same generates a seismic motion of the soil that certainly does not depend on its sporadicity in the study area. In this perspective, the anti-seismic design parameters must take into account the magnitude values defined according to the seismic history and seismotectonics, as required by the Neo-Deterministic Seismic Hazard Assessment (NDSHA) approach, rather than being reduced or increased depending on the greater or lesser earthquake sporadicity, as foreseen by some people, adopting the probabilistic approach (Probabilistic Seismic Hazard Assessment [PSHA]).

Consequently, to move from a perspective focused on response to emergencies to a new perspective based on prevention and sustainability, it is necessary to follow the neo-deterministic approach (NDSHA) to guarantee prevention and hence saving human lives.

NDSHA dates back to the turn of millennium. It is the second millennium scenario- and physics-based multidisciplinary approach for the evaluation of seismic hazard, proven reliable by 20 years of experiments in many countries worldwide. Scenario-based Seismic Hazard Analysis (SSHA) and Maximum Credible Seismic Input (MCSI) are well-established methods, which are part of NDSHA evaluation.

It should be emphasized the importance of the validity of one of the basic principles of geology first suggested by James Hutton in *Theory of the Earth* published in 1795. The principle dictates that the geological or physical phenomena that operate now have always acted with the same intensity in the past geological times, and what happened in the past may happen in the present and will happen in the future, with a caveat toward the concept of "return period." In other words, what happened in the past can happen, but from time to time in the present and in the future.

Noting the fluctuation in specified design values that occurs from code edition to code edition, structural engineers have expressed disbelief in the validity of the science upon which the maps are based and dissatisfaction with the ever-changing design requirements for buildings. Furthermore, as the definition of the maps has become more complex, designers have lost an understanding of the intent of the maps and what they represent. Importantly, the maps portray precision in the design values that is inappropriate, given the substantial uncertainty in the values portrayed. The legislation hence should be based on NDSHA approach, able to overcome most of, if not all, the obvious limitations and serious misconceptions of other prevailing approaches.

In the following, we supply a series of papers that reviews and updates the NDSHA research and the results obtained so far in Africa, America, Asia, and Europe, a collection of evidences that hopefully will induce responsible people and authorities to consider more reliable procedures for SHA evaluation.

In Chapter 1, Vladimir Kossobokov (*Hazard, Risks, and Prediction*) introduces the state-of-the art approaches aimed at reduction of disaster risks demonstrating that although science cannot remove, yet, people's ignorance and favor for illusion regarding reality, it can deliver reliable operational recommendations on the level of natural risks for decision-making in regard to engineering design, insurance, and emergency management. The source of widespread scientific crisis lies in misuse of science, like in probabilistic seismic hazard analyses evidently misleading to unacceptable levels of disaster. On the contrary, the neo-deterministic approach appears to set an innovative standard for Reliable Seismic Hazard Assessment.

In Chapter 2, Jens-Uwe Klugel (*Seismic hazard assessment from the perspective of disaster prevention — Part I: requirements and state of the art; Part II: procedure and practical example*) concludes, after analyzing the key characteristics, possible strengths and limitations of deterministic and probabilistic approaches, including the latest developments of both methodologies, NDSHA and PSHA, that only the deterministic methodology provides a robust and flexible enough basis for the development of a disaster resilient design for critical infrastructures (Part I) and outlines the procedure for seismic hazard assessment (SHA) for the development of disaster resilient design of critical infrastructures and lifelines (Part II). The key element of this methodology is development of a damage-consistent seismic hazard using (i) site intensity as the leading seismic hazard parameter and (ii) NDSHA approach to seismic hazard analysis to achieve the required disaster resilience. The procedure includes the incorporation of a safety factor which is based on the prediction of an upper bound of the energy content of the next record strong earthquake to develop the ensemble of cascading time histories. The hazard results can be applied in a graded, performance-based approach for the design of critical infrastructures. The application of the methodology for reassessment of the seismic design basis of a nuclear power plant is presented.

In Chapter 3, Paolo Rugarli (*The View of a Structural Engineer about Reliable Seismic*

Hazard Assessment) shows that the policy to seismic design of the last 40 years needs upgrading: civil engineers must be aware that the use of PSHA may result in the design of unsafe buildings. This key issue for structural engineers involved in the development of reliable structural analysis software, trying to avoid the spreading of misleading results, requires a great change in seismic hazard evaluation. All the important results in seismic hazard assessment reached in the last 30 years or so, NDSHA evaluation, must be considered in the next versions of the standards and explicitly taken as reference approach.

In Chapter 4, Efraim Laor and Benedetto De Vivo (*Disaster Prediction and Civil Preparedness*) discuss the potential role of NDSHA in the preparedness, mitigation, and management of earthquake disasters. The authors highlight the importance of NDSHA approach in the paradigm shift from disaster reduction to reduction of disaster risk, which should change the community mainstream understanding of sustainable infrastructure.

In Chapter 5, Mattia Crespi, Vladimir Kossobokov, Antonella Peresan, and Giuliano F. Panza (*The Integration between Seismology and Geodesy for Intermediate-Term Narrow-Range Earthquake Prediction according to NDSHA*) argument that earthquakes cannot be predicted with ultimate precision, so that the progressive reduction of the prediction uncertainty in space and time is an evergreen task, both from the scientific point of view for the intrinsic complexity of seismic phenomenon and for its high societal relevance. To this aim, well-tested algorithms exist (CN, M8, and M8S) for intermediate-term middle-range prediction. The authors review the fundamental ideas of an integrated approach based on the synergy of high-density geodetic observations (GNSS and SAR) and seismological information, able to achieve the intermediate-term narrow-range earthquake prediction.

In Chapter 6, Alexander Soloviev (*Modelling the block-and-fault structure dynamics with application to studying seismicity and geodynamics*) overviews modeling of the lithosphere block structure dynamics. The seismic region in the mechanical model is considered to be a structure of perfectly rigid blocks, separated by infinitely thin flat faults, where deformations and stresses arise, causing earthquakes. The results obtained by numerically simulating the dynamics of various block structures, including those that approximate the Earth specific seismic regions, show that the model is a useful tool for studying the effect of fault geometry and block movements on seismicity properties.

In Chapter 7, Alexander Gorshkov and Alexander Soloviev (*Morphostructural zoning for identifying earthquake-prone areas*) examine information on potential earthquake sources as a key starting issue for seismic hazard assessment. They present a phenomenological approach for identifying possible locations of strong earthquakes and its application for the Italian region. The methodology hypothesizes the nucleation of strong earthquakes at morphostructural nodes formed at the intersections of lineaments detected by formalized morphostructural zoning. Pattern recognition techniques pinpoint earthquake-prone nodes based on a wide set of geophysical and geological data characterizing nodes.

In Chapter 8, Antonella Peresan and Leontina Romashkova (*Earthquake forecasting and time-dependent Neo-Deterministic Seismic Hazard Assessment in Italy and surroundings*) prescribe an operational procedure for time-dependent seismic hazard assessment that has been developed and integrates intermediate-term middle-range earthquake forecasts from pattern recognition analysis (by CN and M8S algorithms) with the scenario-based NDSHA. The authors provide a review of the results from rigorous prospective testing of the integrated procedure, which is ongoing for the Italian territory since 2006. The results obtained so far, including analysis of the statistical significance of issued forecasts, support reliability of the time-dependent scenarios associated with CN predictions.

In Chapter 9, Fabio Romanelli, Giorgio Altin, and Maurizio Indirli (*Spreading NDSHA Application from Italy to other Areas*) provide an in-depth discussion of the NDSHA application to the cities of Rome, Valparaiso, and Trieste illustrating the existing possibilities for a local scale analysis of earthquake hazard and associated risks.

In Chapter 10, Maria Rosaria Costanzo and Concettina Nunziata (*S-wave velocity profiling for site response evaluation in urban area*) discuss average one-dimensional shear wave velocity models obtained in the densely urbanized city of Napoli (Italy), through frequency-time analysis and nonlinear inversion methods applied to cross-correlation of synchronous ambient noise recordings at two sites. The comparison of the spectral amplifications computed along a section in the historical center, for the 1980 earthquake (MW 6.8), with ellipticity and H/V spectral ratios, at specific sites, evidences the key role of sound seismostratigraphies.

In Chapter 11, Franco Vaccari and Andrea Magrin (*A User-friendly Approach to NDSHA Computations*) describe the web-based software XeRiS that allows to generate a comprehensive suite of realistic ground motion parameters for a scenario earthquake modeling with different level of detail. XeRiS is a powerful tool useful for both geophysical and earthquake engineering community.

In Chapter 12, Mohamed El Gabry, Hani Hassan, and Hesham Hussein (*Recent Applications of NDSHA: Seismic Input for High Rise Buildings in Egypt New Capita*l) make a review and update of the local and regional seismic sources that may affect the Central Business District (CBD) project site. Both local and distant earthquakes have been incorporated to produce NDSHA synthetic seismograms (displacement, velocity, and acceleration) and spectral accelerations to be used by the structural designers. The estimated NDSHA PGA median value (50th percentile) is about 0.16 g, which is comparable to 0.15 g PGA of the Egyptian building code for the zone where the CBD is located, but the 84th and 95th percentile estimated NDSHA PGA reach 0.23 and 0.28 g, respectively.

In Chapter 13, Gian Paolo Cimellaro, Melissa De Iuliis, and Sebastiano Marasco (*Neo-deterministic method to assess the seismic performance of water distribution networks*) investigate the service failures of water distribution networks (WDNs) due to natural and man-made hazards that may incur consequences to public health, economic security, and social welfare. They propose a resilience index (R) of a WDN as the product of three indices: (1) the number of users temporarily without water, (2) the water level in the tank, and (3) the water quality. To demonstrate the applicability of the methodology, different disruptive scenarios have been implemented in a small town in southern Italy.

In Chapter 14, Lalliana Mualchin (*Seismic Hazard Analysis in a Historical Context: Experience at Caltrans and Elsewhere*) recalls his vivid personal experience about how probabilistic hazard assessment approach had been started in California and was exported out all over the world and how difficult it was to pass through the oppositions to applying deterministic Maximum Credible Earthquake (MCE) approach in preparing twice the state seismic hazard map of California.

In Chapter 15, Benedetto De Vivo, Efraim Laor, and Giuseppe Rolandi (*Where There's No Science - Probabilistic Hazard Assessment in Volcanological and Nuclear Waste Settings: Facts, Needs and Challenges in Italy*) give reasons for poor decisions in hazard assessments for volcanological and nuclear waste settings in Italy as the failure of providing scientifically correct recommendations. Italian scientists often offer recommendations based on probabilistic assessments to meet the political demands rather than oppose those contradicting scientific and ethical grounds. The article discloses this malpractice concerning the largest civil hospital in southern Italy on the slope of Mt. Vesuvius, active volcano, and planning the site of radioactive waste disposal near the town of Scanzano Jonico in Basilicata. The authors suggest expanding the basic principles of NDSHA to reliable estimations of other natural hazards and mitigation of associated risks.

In Chapter 16, Junbo Jia (*Seismic Hazard and Earthquake Engineering for Engineering Community*) discusses the emerging topic of offshore earthquake engineering. Earthquakes and tsunamis have great potential to cause damage to offshore infrastructures and require the due development of earthquake detection, description, and evaluation technology to obtain earthquake resistant forms and techniques of construction for offshore platforms, offshore bridges, oil and gas exploration projects, and the provision of basic material and theoretical support for further improvement of specifications and standards. NDSHA supplies reliable hazard estimation for engineering applications and implementation in design codes and standard suitable for the protection of offshore infrastructures as well.

In Chapter 17, Zhenming Wang, Seth Carpenter, and Edward Woolery (*Scenario-based Seismic Hazard Analysis and Its Applications in the Central United States*) applied Scenario Seismic Hazard Analysis (SSHA), a part of NDSHA, to derive seismic hazards in the central United States, Kentucky in particular, and faced the challenge caused by the large uncertainties in earthquake locations, magnitudes, occurrence rate, and ground motions, which in turn led to large numerical uncertainty in probabilistic ground motion hazard estimate and makes communicating, understanding, and using the hazard maps for the central United States difficult. The SSHA hazard information has been used for engineering design and evaluation of bridges and highway facilities, as well as other safety considerations in the central United States.

In Chapter 18, Mihaela Kouteva-Guentcheva, Carmen Cioflan, Ivanka Paskaleva, and Giuliano Panza (*NDSHA Achievements in Central and South-Eastern Europe*) provide a summarizing overview of the up-to-date achievements of the multi-aspect power of the NDSHA, supported by numerous applications. The authors point out to the major advantage to involve in the estimates of the site response all factors controlling the ground motion (seismic-mechanical features of the propagating media and the seismic source) and recommend using NDSHA for engineering design, but, when PSHA is required based on national regulations, to compare the results/output of PSHA with that of physics scenario-based analysis of NDSHA.

In Chapter 19, Concettina Nunziata and Maria Rosaria Costanzo (*Application of NDSHA to Historical Urban Areas*) present the NDSHA simulation of the telluric motion for two urban areas, heavily damaged by recent and historical earthquakes: Poggio Picenze, for the April 6, 2009 (MW 6.3) event, and Napoli, for the 1980 (MW 6.8) and for the strongest historical 1456 and 1688 earthquakes. Consistency exists between computed ground accelerations and intensity data (IMCS) if we attribute MW 6.6 to 1688 and 6.9 to 1456 earthquakes, respectively. If the literature magnitudes are considered, higher values of the telluric motion are expected for earthquakes like the 1688 with magnitude 7 and the 1456 with magnitude 7.3, to be considered conservative scenario earthquakes.

In Chapter 20, Carmen Ortanza Cioflan, Elena Florinela Manea, and Bogdan Felix Apostol (*Insights from Neo-Deterministic Seismic Hazard Analyses in Romania*) provide a review of state-of-the-art studies of seismic hazard with emphasis on the complex physics-based waveform modeling for the territory of Romania. In the context of the Vrancea intermediate-depth seismicity, the innovative NDSHA has proved to be very efficient at national and local scales realistically reproducing the macro-seismic, as well as the local site amplification for the city of Bucharest.

In Chapter 21, Mihaela Kouteva-Guentcheva, Ivanka Paskaleva, and Giuliano Panza (*NDSHA in Bulgaria*) apply NDSHA to the Bulgarian territory, exposed to high seismic risk from local shallow and regional intermediate-depth earthquakes. Structural engineering needs alternative representation of the seismic loading via accelerograms. The available strong motion database is not representative of the real hazard and NDSHA evaluation supplies databases of realistic synthetic seismograms readily applicable for earthquake engineering purposes. The comparison between the results derived from the real databank and the results obtained from the synthetic database compiled using NDSHA is fully satisfactory for displacements and corner periods.

In Chapter 22, Elena Dumova-Jovanoska and Kristina Milkova (*NDSHA-based vulnerability evaluation of pre-code buildings in Republic of North Macedonia; novel experiences*) provide a methodology for seismic vulnerability evaluation of existing precode structures, using a multidisciplinary approach. As a result, region-specific vulnerability and reliability curves that relate the peak ground acceleration values to the probability of exceedance of a certain damage state have been presented. The results highlight the advantage of using site-specific NDSHA response spectra as seismic input, as the damage reports from earthquakes that struck Ohrid in 2017 have confirmed the merits of the applied approach.

In Chapter 23, Sokol Marku, Rapo Ormeni, and Giuliano Panza (*Seismic characterization of Tirana - Durrës - Lezha region (northwestern Albania) and analysis effort through NDSHA method*) aim to suggest the most advanced and reliable way of assessing regional seismic hazard and risks. The strongest seismic events that struck Albania have occurred into an area extended between Shkumbini River and city of Shkodra. The region is known as one of the most active seismogenic zones in Albania and is located between some of the most important seismogenic lineaments of the country. Comparing PSHA and NDSHA results with 2019 ground motion values proves that NDSHA is a more reliable method.

In Chapter 24, Mariano García-Fernández, Franco Vaccari, María-José Jiménez, Andrea Magrin, Fabio Romanelli, and Giuliano Panza (*Regional application of the NDSHA approach for continental seismogenic sources in the Iberian Peninsula*) apply two combined seismogenic source models: polygonal zones and nodes obtained by morphostructural analysis. Hazard maps of maximum ground displacement, Dmax, and maximum ground velocity, Vmax, up to a maximum frequency of 1 Hz, and design ground acceleration, DGA, are produced. NDSHA results show largest Dmax values in central-western

Portugal and similar high Vmax both in the west and in the east of the Iberian Peninsula. DGA reaches its highest values in central-western Portugal and in eastern Spain.

In Chapter 25, Yan Zhang, Lihua Fang, Fabio Romanelli, Zhifeng Ding, Shanghua Gao, Changsheng Jiang, and Zhongliang Wu (*NDSHA Applied to China*) analyze the activities of Chinese seismologists to reduce damage from earthquakes, in particular, new approaches to earthquake forecast/prediction. The authors describe in detail the application of NDSHA approach to the territory of China and the important role of cooperation with Italian scientists, the founders of the NDSHA approach. The results obtained in about two decades, as well as the prospects for further research are of undoubted interest for specialists in the field of seismic hazard and risk assessment.

In Chapter 26, Imtiyaz Parvez (*Application of Neo-Deterministic Seismic Hazard Assessment to India*) supplies a comprehensive validation of NDSHA in India and neighboring region at national, regional, and local scales. The pre-disaster mitigation effort based on NDSHA may drive seismic and civil engineers who wish to undertake detailed studies of earthquake hazard, especially in the eastern Himalayan region, eastern and western India, and some big cities such as Delhi and Kolkata. NDSHA evaluation supplies now a preventive tool that can be used, without having to wait for the next great earthquakes to occur, for the safe design of buildings and other infrastructure in the country.

In Chapter 27, Farhana Sarwar, Franco Vaccari, and Andrea Magrin (*Neo-Deterministic Seismic Hazard Assessment for Pakistan*) discuss the preliminary regional seismic hazard map for Pakistan and adjoining regions published in 2018. The authors update the seismic hazard assessment for Pakistan by using a new earthquake catalog and the latest computer codes for the NDSHA evaluation. The comparison between probabilistic PSHA and NDSHA maps for Pakistan shows that the currently adopted PSHA maps generally underestimate the level of ground shaking that might be expected for future events.

In Chapter 28, Tahmeed M. Al-Hussaini, Ishika N. Chowdhury, Hasan al Faysal, Sudipta Chakraborty, Franco Vaccari, Fabio Romanelli, and Andrea Magrin (*Neo-Deterministic Seismic Hazard Assessment Studies for Bangladesh*) investigate the complex regional tectonic environment and limited information on seismic sources and fault zones, under ongoing collaboration between University of Trieste and Bangladesh University of Engineering and Technology. Various scenario computations, including NDSHA-MCSI, have been performed for Bangladesh. Results indicate higher seismic hazard than the BNBC-2020 code provisions for the major cities of Sylhet and Chittagong, which warrants more extensive source-specific studies of the impact of major earthquakes on known faults, for which NDSHA-MCSI is well suited.

In Chapter 29, Habib Rahimi and Mehdi Rastgoo (*Application of NDSHA at Regional and Local Scales in Iran*) describe NDSHA for Alborz region in the north of Iran, including the two validation tests at local scale performed for the city of Tehran. The validation tests show that the hybrid technique, which combines modal summation and finite difference methods, can be used for computation of the acceleration response spectra along the two-dimensional sediment structure of the city and different earthquake scenarios with sources on the active faults around Tehran.

In Chapter 30, Irwandi Irwandi (*Application of Neo-Deterministic Seismic Hazard Analysis to Sumatra*) analyzes earthquake hazard in Indonesia at two different scales:

the regional scale of Sumatra Island and the local scale of Banda Aceh city. The NDSHA regional and microzonation maps based on the available information on the Earth's structure, seismic sources, and the level of seismicity of the investigated area represent a milestone for Reliable Seismic Hazard Assessment throughout Indonesia, a country exposed to extreme earthquake risks.

Evidently, the NDSHA applications outscore the widespread PSHA by taking advantage of a synergy between to-date available Pattern Recognition of Earthquake Prone Areas (PREPA), Intermediate-Term Earthquake Prediction (ITEP) of different spatial accuracy, Scenario-based Seismic Hazard Analysis (SSHA), Unified Scaling Law for Earthquakes (USLE) that accounts for fractal distribution of seismic occurrence, and Geodetic Data Analysis (GDA) of GPS, GSSN, and other determinations.

The synergy of PREPA × USLE × ITEP × GDA × MCSI × SSHA applies to a pretty wide spectrum of geophysical observables and allows us to deliver user-specific NDSHA products, which are tested to be reliable, realistic, and useful evaluation and mapping of apparently time-dependent seismic hazard and associated risks. Of course, although each member of the synergy is relevant in seismic hazard assessment (in different terms), it is MCSI × SSHA that provides a quantitative output of seismic input for the structural engineer community at the final stage of NDSHA.

NDSHA evaluation aims at minimizing the effect of possible bad data massaging. Therefore, the general enveloping philosophy developed and applied within NDSHA evaluation should be systematically extended to other types of hazards such as volcanic eruptions, landslides, wildfires, floods, hurricanes, and other dangerous happenings, to provide most reliable input for assessing associated risks.

We believe that perhaps a comment on the use of intermediate values in any macroseismic intensity scale is important and probably warranted here, because they have caused several drawbacks when they have been subsequently used to derive quantified estimates of hazard and seismic design parameters. Any intensity scale is defined as "A sequence of Natural Ordinal Numbers, i.e., a scale in which each number tells the position of something in a discrete scale of integers, such as I, II, III, IV, V, etc." Within our combined experience, we cannot locate any problem for which the artifact of introducing non-integer intensity values is both a solution and an advantage. The illusion of high precision does little to improve accuracy in the final product resulting from using this pre-instrumental system for recording the sizes of earthquakes as witnessed by their effects. Accuracy, we believe, has more to do with both a knowledge-based consideration and a comprehensive integration of all the other judgments that have to be made.

The declared legacy of the Global Seismic Hazard Assessment Program (GSHAP) is to establish a common framework to evaluate the seismic hazard over geographical large scales, i.e., countries, regions, continents, and finally the globe. Its main product, the global seismic hazard map, was meant to be a milestone, unique at that time and to serve as the main PSHA reference worldwide. Today, for most of the Earth's seismically active regions in Europe, Northern and Southern America, Central and Southeast Asia, Japan, Australia, and New Zealand, the GSHAP hazard map is proven outdated, very often wrong as it has been shown on many occasions: GSHAP was proven wrong after the 2010 Haiti disaster; after the 2011 Tohoku mega-earthquake, it was even shown that the GSHAP maps could have been proved misleading at the time of their official publication in 1999.

The next generation of PSHA models is at the base of the Global Earthquake Model (GEM) products (the most recent one being MPS19 for Italy). The GEM Foundation released, at the end of 2020, several national and regional earthquake hazard and risk models and other global model digital data products in the observance of this year's International Day for Disaster Risk Reduction theme—the role of national and local disaster risk reduction strategies on good disaster risk governance.

This has been a smart move from the GSHAP advocates. In fact, as reported in this book, some 20 years after its launch, it has been possible to prove that GSHAP is totally unreliable. In fact, several are the evidences of how useless and misleading can be most of its published results. GSHAP is unreliable as witnessed by the more than 700,000 lives lost between 2000 and 2011, when 12 of the world's deadliest earthquakes have occurred where PSHA had predicted much more lower seismic hazard. With the same general philosophy as GSHAP, plus some cosmetics, some 10 years ago GEM was proposed. GEM is on the wrong track, if it continues to base seismic risk estimates on a refined "standard method" to assess seismic hazard. How long it will be necessary to wait to prove that GEM is as wrong as GSHAP? Should Science Community wait for a decade to find GEM is as wrong as GSHAP?

NDSHA ? PSHA

The purpose of this volume is to promote establishing a new paradigm of Reliable Seismic Hazard Assessment, a synergy of the up-to-date available scientific knowledge that guarantees prevention and reduction of unacceptable losses rather than cure the consequences of disasters.

The book is essential reading for geologists, geophysicists, geochemists, exploration geologists, seismologists, volcanologists, most categories of engineers from civil to mechanical, from chemical to computer, from biomedical to electrical; disaster and emergency managers, officials at governmental and municipality echelons, logistic officers of military services, infrastructure entrepreneurs, financial and insurance industry employees, multidisciplinary students, researchers, and professors.

Many authors who participated in writing this book keep being inspired by the innovative research of Vladimir Isaakovich Keilis-Borok (July 31, 1921–October 19, 2013) and, in particular, by his ability to find simplicity in complexity, active style, scientific intuition, exceptional warmth of soul and humanity. Catastrophic earthquakes and other hazardous events addressed in his studies pose unacceptable threats to people. "My main trouble," he says, "is feeling of responsibility" (Los

Angeles Times, July 9, 2012). Keilis-Borok had founded a unique institute where pure mathematicians worked jointly with physicists and geologists in collaboration with the world famous experts from mathematics, physics, economics, social sciences, law enforcement, environment protection, disaster management, and the government (including Mikhail A. Sadovsky, Izrail M. Gelfand, Michele Caputo, Leon Knopoff, Clarence R. Allen, Frank Press, Leonid V. Kantorovich, Vinod K. Gaur, Keiiti Aki, Alberto Giesecke, Allan Lichtman, Raymond Hide, Claude Allègre, Yakov G. Sinai, Giuliano F. Panza, Dmitri V. Rundqvist, Michael Ghil, and many others). Upon invitation from Mohammad Abdus Salam, founder of International Center for Theoretical Physics (ICTP, Miramare, Trieste, Italy), Keilis-Borok co-organized with Panza, as ICTP consultant, a series of workshops starting with the first one on *Pattern Recognition and Analysis of Seismicity* (December 5–15, 1983) and ending with Advanced School on *Understanding and Prediction of Earthquakes and Other Extreme Events in Complex Systems* (September 26–October 8, 2011). In 1991, Keilis-Borok and Panza established "Structure and Nonlinear Dynamics of the Earth" SAND Group at the Abdus Salam ICTP. Keilis-Borok and his school revolutionized disaster prediction studies as the frontier problem of geosciences. He broke the barriers between high theory, numerical modeling, and data analysis for the purposes of implementation into the practice of investigation the hot, itchy, and often controversial problems. His last publication appeared in the first issue of *International Journal of Disaster Risk Reduction* describing a missed opportunity for disaster preparedness in response to advance prediction of the March 11, 2011 Great East Japan Earthquake, focusing on how reasonable, prudent, timely, and cost-effective decisions can be made to reduce the consequences of damaging earthquake.

For his scientific excellence, Vladimir I. Keilis-Borok was elected to the American Academy of Arts and Sciences (1969), to the US National Academy Sciences (1971), to the Russian Academy of Sciences (1987), to the Royal Astronomical Society (1989), to the Austrian Academy of Sciences (1992), to the Pontifical Academy of Sciences (1994, Council Member since 1996), and Academia Europaea (1999). In 1995, he received Doctor Honoris Causa from Institut de Physique du Globe de Paris. In 1998, European Geophysical Society awarded Prof. Vladimir I. Keilis-Borok with the first Lewis Fry Richardson Medal "for his outstanding contributions to the study of the nonlinear dynamics of the lithosphere, in particular to the development of the concept that the active lithosphere is a hierarchical nonlinear system."

EARTHQUAKES AND SUSTAINABLE INFRASTRUCTURE

Neodeterministic (NDSHA) Approach Guarantees Prevention Rather Than Cure

Edited by

GIULIANO F. PANZA, VLADIMIR G. KOSSOBOKOV, EFRAIM LAOR AND BENEDETTO DE VIVO

Earthquakes and Sustainable Infrastructure: Neodeterministic (NDSHA) Approach Guarantees Prevention Rather Than Cure communicates in one comprehensive volume the "state-of-the-art" scientific knowledge on earthquakes and related seismic risks. Earthquakes occur in a seemingly random way, and in some cases, it is possible to trace seismicity back to the concept of deterministic chaos. Therefore, seismicity can be explained by a deterministic mechanism that arises as a result of various convection movements in the Earth's mantle, expressed in the modern movement of lithospheric plates fueled by tidal forces. Consequently, to move from a perspective focused on response to emergencies to a new perspective based on prevention and sustainability, it is necessary to follow this neo-deterministic approach (NDSHA) to guarantee prevention, saving lives, and infrastructure.

So far, the neo-deterministic method has been successfully applied in numerous metropolitan areas such as Delhi (India), Beijing (China), Naples (Italy), Algiers (Algeria), Cairo (Egypt), Santiago de Cuba (Cuba), and Thessaloniki (Greece). *Earthquakes and Sustainable Infrastructure* includes case studies from these areas, as well as suggested applications to other seismically active areas around the globe. This book is essential reading for geophysicsts, geochemists, seismic engineers, and those working in disaster preparation and prevention.

Key Features

- The only book to cover earthquake prediction and preparation from a neo-deterministic (NDSHA) approach
- Includes case studies from metropolitan areas where the neo-deterministic method has been successfully applied
- Editors and authors include top experts in academia, disaster prevention, and preparedness management

About the Editors

Giuliano F. Panza, former full professor of Geophysics, Trieste University and Head SAND Group Abdus Salam ICTP Trieste, is Emeritus Honorary professor CEA Beijing, Honorary professor BUCEA Beijing.

Vladimir G. Kossobokov is a Chief Scientist at Institute of Earthquake Prediction Theory and Mathematical Geophysics, Russian Academy of Sciences, and former Vice President of the IUGG Commission of Geophysical Risk and Sustainability.

Efraim Laor is a co-founder and Chief Scientist at National Research Institute for Disaster Reduction (AFRAN), Holon Institute of Technology, a former Chairman of the Government of Israel National Steering Committee for Disaster Reduction.

Benedetto De Vivo is a full professor of Exploration and Environmental Geochemistry at Pegaso On-Line University, Napoli, Italy; Adjunct Professor at Virginia Tech, Blacksburg, VA, USA; Nanjing Univ. and Hubei Polytecnic Univ, Huangshi, China.

On the front cover: In the figure the aoristic, not defined aspect of time, of the Torre dei Modenesi clock without hands is contrasted with the image of roulette, in which each event has its probability and its well-defined "period of return." Inset photo image credit: Paolo Rugarli, all rights reserved.

ISBN 978-0-12-823503-4

9 780128 235034

ELSEVIER

elsevier.com/books-and-journals