Living with Unstable Ground





AGI Environmental Awareness Series

AGI gratefully acknowledges the **publishing partners** for their support of this book and the **AGI Foundation** for its support of the Environmental Awareness Series. For more information about this book and the Series please see the copyright page and inside back cover.

Livingwith Unstable Ground

by Thomas L. Holzer



American Geological Institute in cooperation with

Association of Environmental & Engineering Geologists ATC Applied Technology Council & ATC Endowment Fund **ZUSGS** U.S. Geological Survey

About the Author

Thomas L. Holzer is a research engineering geologist with the U.S. Geological Survey, where he has worked since 1975. He also is on the consulting faculty at Stanford University and has taught at the University of Connecticut. He received his B.S.E. from Princeton University and his Ph.D. from Stanford University. His research career has focused primarily on ground failure and how to reduce its impact on people and the built environment. His interests range from ground failures caused by humans to natural ones. He has authored more than 100 publications on ground failure, including editing Reviews in Engineering Geology volume VI, *Maninduced Land Subsidence*, published by the Geological Society of America. He has conducted many post-earthquake investigations, both domestically and internationally. He is presently developing a new methodology for mapping liquefaction hazard associated with earthquakes.

In 1995, he received the Distinguished Service Award of the Hydrogeology Division of the Geological Society of America. In 1998, he was the Geological Society of America and Association of Environmental and Engineering Geologists Richard H. Jahns Distinguished Lecturer. He is a fellow of the Geological Society of America and a member of the American Geophysical Union, the Earthquake Engineering Research Institute, and the Seismological Society of America.

American Geological Institute 4220 King Street Alexandria, VA 22302 (703) 379-2480

www.agiweb.org

To purchase additional copies of this book or receive an AGI publications catalog please contact AGI by mail or telephone, send an e-mail request to **pubs@agiweb.org**, or visit the online bookstore at **www.agiweb.org/pubs**.

Copyright 2009 by American Geological Institute All rights reserved. ISBN: 0-922152-82-9 978-0-922152-82-7 Project Management: Julia A. Jackson Design: DeAtley Design

Contents

Publishing Partners 4 Preface 5

It Helps To Know 7

What the Environmental Concerns Are7Why Ground Becomes Unstable8Where Unstable Ground Occurs10How to Live with Unstable Ground10

Problem Soils 13

Soft Soils 13 Organic Soils 16 Expansive Soils 18 Collapsible Soils 20 Frozen Soils 22 Liquefiable Soils 24

Slope Movement 29 Slides 29 Flows 31 Soil Creep 31 Earthquake Triggering 32 Living with Slope Movement 33

Catastrophic Collapse 35

Caverns 35 Underground Excavations — Mines and Tunnels 38

Regional Ground Movement 41

Land Subsidence Caused by Withdrawal of Groundwater and Petroleum 41 Crustal Movement During Earthquakes 44 Subsidence of the Mississippi River Delta 48

Guidelines for Living with Unstable Ground 51

Geologic Mapping and Engineering Design 51 Construction Codes and Land-use Management 52 Regulation of Resource Development 54 Government Corrections to Market Distortions 55 Insurance 55 Living with Unstable Ground 56

Glossary 58 Sources of Additional Information 60 Credits 62 Index 64

Publishing Partners



American Geological Institute

(AGI), founded in 1948, is a federation of 45 geoscience societies. AGI provides information and education services to its members, promotes a united voice for the geoscience community, plays a major role in strengthening geoscience education, and strives to increase public awareness of the vital role the geosciences play in our use of resources and interaction with the environment.



Satellite view of landslide dam caused by 2005 Kashmir earthquake

(magnitude 7.6).

www.agiweb.org and www.earthscienceworld.org

Association of Environmental and Engineering Geologists (AEG) was founded in 1957 and was incorporated according to the laws of the State of California on June 19, 1960. AEG contributes to its members' professional success and the public welfare by providing leadership, advocacy, and applied research in environmental and engineering geology.

www.aegweb.org

Applied Technology Council (ATC) is a nonprofit, tax-exempt corporation established in 1973 through the efforts of the Structural Engineers Association of California. Support for Living with Unstable Ground came from the ATC Endowment Fund, which supports projects of critical importance to structural engineering design practice, for which funds are not available from traditional funding sources. ATC's mission is to develop and promote state-of-the-art, user-friendly engineering resources and applications for use in mitigating the effects of natural and other hazards on the built environment. ATC also identifies and encourages needed research and develops consensus opinions on structural engineering issues in a nonproprietary format. ATC thereby fulfills a unique role in funded information transfer.

www.atcouncil.org



U.S. Geological Survey (USGS) serves the Nation by providing reliable scientific information to describe and understand the Earth; minimize loss of life and property from natural disasters; manage water, biological, energy, and mineral resources; and enhance and protect our quality of life. USGS has become a world leader in the natural sciences thanks to its scientific excellence and responsiveness to society's needs.

www.usqs.qov