QUANTITATIVE RISK ASSESSMENT (QRA) FOR NATURAL HAZARDS

Edited by Nasim Uddin, Ph.D., P.E. and Alfredo H.S. Ang, Ph.D.

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Introduction—Quantitative Risk Assessment (QRA) for Natural Hazards

This introduction and executive summary covers the origins of this monograph as a sequel to the five previous monographs generated by ASCE CDRM members and other volunteers as well as a brief synopses of the papers included in this monograph.

The Monograph as a Sequel

This monograph, produced by the Council on Disaster Risk management (CDRM), is a sequel to five previous monographs, *Acceptable Risk Processes: Lifelines and Natural Hazards* (2002) and ASCE CDRM Monograph No. 1, *Infrastructure Risk Management Processes: Natural, Accidental and Deliberate Hazards* (2006), both edited by Craig Taylor and Erik VanMarcke; *Disaster Risk Assessment and Mitigation* (2008) edited by Nasim Uddin and Alfredo Ang; *Multihazard Issues in the Central United States* (2008), edited by James Beavers; and *Windstorm and Strom Surge Mitigation* (2009) edited by Nasim Uddin.

Genesis of This Monograph

Recent events throughout the world have drawn attention to the vulnerability of infrastructure to natural hazards. Moreover, a risk analysis of any asset is not complete unless natural hazards are considered. Natural hazards include, at a minimum, the effects of earthquake, hurricane, tornado, and flood. Each of these events can be considered for any particular asset by determining the expected frequency of the event and estimating the consequences. The vulnerability of the asset is dependent upon the type of structure and how it will be affected by the initiating event. Additional natural hazards, such as ice storms, extreme cold weather, wildfire, avalanche, tsunami, landslide, mud slide, and others, should be included if the probability of occurrence and the consequences are higher than the four natural hazards mentioned above. This monograph is based on the ASCE tutorial and workshop organized by Prof. Alfredo Ang of the University of California at Irvine titled "Engineering Application of QRA" held during the fourth Civil Engineering Conference in the Asia region (4th CECAR, June 25-27, Taipei, 2007). The QRA program included a morning session and an afternoon session.

In the morning session, Prof. Ang presented a tutorial titled "Introduction to Fundamentals for Quantitative Risk Assessment." The first paper of the monograph is based on the tutorial and titled "An Application of Quantitative Risk Assessment in Infrastructures Engineering," which summarized the practical aspect of quantitative risk assessment (QRA) highlighting engineering decision-making with emphasis on the design of civil infrastructures. Besides the estimation of the expected risk measure, the distribution of the risk resulting from the uncertainty in the calculated

risk is equally important; the latter provides more complete information and permits the decision-maker the option of selecting a risk-averse measure to minimize the error (or increase the confidence) in making the right decision. Quantitative risk is also of significance for developing risk-based optimal design of infrastructures for mitigating risks from natural hazards. The process is illustrated numerically with a hypothetical example of the risk assessment (including risk reduction) and of retrofitting the levee system in New Orleans assuming that an assessment is performed in 1990—15 years prior to the occurrence of Katrina in 2005. The practical implementation of QRA is also emphasized.

The next six papers on the monograph are based on the six full papers presented in the afternoon session.

In the monograph's second paper titled *Quantitative Risk Analysis Applied to Dams*, Prof. Erik Vanmarcke explored the value and use of probabilistic risk assessment, with a focus on an action-oriented approach to decision-making applicable to (systems of) dams, in which the engineer estimates dam failure risks and their consequences and quantifies the effectiveness and economic benefits of alternative strategies aimed at risk reduction. The methodology presented in his paper provides a format for summarizing and accounting for (in the case of dams) data about past dam failures, the relative frequency of various causes of failure, the consequences of failure, and the effectiveness of different risk mitigation measures. It facilitates communication about risk and the costs and benefits of reducing risk among stakeholders in decision situations involving mitigation of hazards. Most importantly, it enables quantifying the benefits of actions aimed primarily at risk reduction. In this broad and varied context, the concepts and tools of quantitative risk analysis appear essential to advancing the art and practice of civil engineering.

In the third paper, *Risk Assessment for Wind Hazards*, Prof. Nasim Uddin discussed current wind-related quantitative risk assessment methodologies with examples. Recent research developments on modeling wind speed extremes associated with tropical cyclones and tornadoes are also briefly summarized in the paper.

Prof. Anne Kiremidjian, with co-authors Evangelos Stergiou and Renee Lee in their paper titled *Quantitative Earthquake Risk Assessment*, presented a brief summary of earthquake risk assessment methods. The method considers ground motion, liquefaction, and landslide hazards as well as the contribution of direct physical loss and functional loss, and can be applied either to a single structure or to group of structures that are spatially distributed in a region exposed to earthquakes. Furthermore, lifeline systems, such as water, power, communications, and transportation systems, can be analyzed with the consideration of the network flow through the system. For either a single structure or a distributed system, the risk can be due to direct damage or to loss of functionality. An example demonstrates the application of the method to a transportation network system within the San Francisco Bay Region.

In their paper *Risk Assessment for Bridge Decision-Making,* Prof. Dan M. Frangopol and Thomas B. Messervey investigate how the inclusion of risk can enhance the design, assessment, and management of bridge structures. The effect of obtaining more precise information is modeled through the reduction of the standard deviation of random variables within performance functions used to model a structure's performance over time within a reliability analysis. Similarities are investigated between the risk-based decision-making process and reliability-based life-cycle management (LCM) methods with the intent of combining synergistic benefits from each approach. A pre-posterior analysis in a Bayesian framework is conducted to demonstrate how life-cycle cost analysis can be utilized to facilitate the design of monitoring solutions by establishing cost/benefit benchmarks for consideration by bridge managers.

Prof. Bilal M. Ayyub and William L. Mcgill in their paper, *An All-Hazards Methodology for Critical Asset and Portfolio Risk Analysis,* develop a quantitative all-hazards methodology for critical asset and portfolio risk analysis (CAPRA) that considers both natural and human-caused hazards. The data requirements for CAPRA include both historical information and expert opinions, and uncertainty is accommodated as appropriate using standard techniques for uncertainty propagation and representation. A general formula for all-hazards risk analysis is obtained that resembles the traditional model based on the notional product of consequence, vulnerability, and threat, though with clear meanings assigned to each parameter. The methodology is briefly introduced and demonstrated using several illustrative examples based on notional information.

In the final paper of the monograph, *A Methodology for the Risk Analysis and Management of Protected Hurricane-Prone Regions*, Prof. Ayyub introduces a quantitative risk analysis methodology for hurricane prone areas protected by a hurricane protection system. The methodology is intended to assist decision-makers and policy-makers, and has the characteristics of being analytic, quantitative, and probabilistic. Quantifying risk using a probabilistic framework produces hazard (elevation) and loss-exceedance rates based on a spectrum of hurricanes according the joint probability distribution of the characteristic parameters that define hurricane intensity and the resulting surges, waves, and precipitation. The hazard is quantified using a probabilistic framework to obtain hazard profiles as elevation-exceedance rates, and the risk is quantified in the form of loss-exceedance rates based on a spectrum of hurricanes determined using a joint probability distribution of the parameters that define hurricane intensity. The proposed methodology will enable decision-makers to evaluate alternatives for managing risk, such as providing increased hurricane protection, increasing evacuation effectiveness, changing land use policy, enhancing hurricane protection system operations, and enhancing preparedness.

In conclusion, the monograph should appeal to all those concerned with safeguarding infrastructures from the effects of natural hazards. With its team of expert contributors, who reflect many years of specialized experience, including the private, governmental, and academic perspectives, the monograph will be a standard reference