DISASTER RISK ASSESSMENT AND MITIGATION

ARRIVAL OF THE SOUTH ASIA TSUNAMI WAVE IN THAILAND

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

ASCE Council on Disaster Risk Management
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ASCE

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WILLIAM JEFFERSON CLINTON

August 16, 2005

Warm greetings to everyone gathered in Los Angeles for the 2005 annual conference of the American Society of Civil Engineers.

America draws great strength from the success and longevity of groups such as yours. From the time of your organization's founding, it has advanced the interests and goals of your members and promoted excellence in your profession -- and excellence in civil engineering leads to a better quality of life for us all.

I was pleased to learn that one of the focuses of this year's pre-conference programs is engineering aspects of the recovery effort in the tsunami region. As the U.N. Special Envoy for Tsunami Recovery, I recently visited countries hard hit by the disaster. It became clear that the rough temporary shelters for survivors were of primary concern -- and, by the same token, the fact that the labor markets are not always equipped to deal with the daunting housing and infrastructure task ahead. Massive damage to schools, medical facilities, and houses will have to be repaired, and we are working to "build back better" rather than replace poverty with poverty.

I am grateful that the civil engineering community in our country is investigating these and other challenges. I am confident that you, our nation, and the international community will continue to be well served by ASCE's dedication to providing its members with avenues to professional growth and to exploring the issues that affect people around the globe.

Best wishes for a productive conference.

Foreword

On October 26, 2005, eminent national and international participants engaged in lively presentations and discussions during a symposium and international roundtable at the American Society of Civil Engineers national convention in Los Angeles. We commend the editors of this monograph, Drs. Uddin and Ang, and their reviewers for benefiting a wider audience with some of these discussions. These papers address perennial issues on how civil engineers can learn from past disasters and work in the commons to prevent great suffering and loss.

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Chapter 1

Disaster Risk Assessment and Mitigation

This introduction and executive summary covers:

- the origins of this monograph as a sequel to two previous monographs generated by the efforts of the members of ASCE CDRM and other volunteers,
- an overview of disaster risk assessment and management processes,
- a brief synopses of the papers included in this monograph, and
- a brief list of significant related publications.

The Monograph as a Sequel

Synopses of Papers in First Monograph

This monograph, produced by the Council on Disaster Risk Management (CDRM), is a sequel to a two previous monographs: *Acceptable Risk Processes: Lifelines and Natural Hazards* (2002) and *Infrastructure Risk Management Processes: Natural, Accidental and Deliberate Hazards* (2006), both edited by Craig Taylor and Erik VanMarcke and published by ASCE.

The first monograph contained mainly technical papers that evaluated procedures used in the acceptable risk processes in lifelines against natural hazards. Considering all the advances in probabilistic seismic hazard analysis over more than three decades, David Perkins elaborated a number of remaining issues having the effect that uncertainties may be significantly higher than the well-developed models indicate. Armen der Kiureghian presented a paper explaining how to apply Bayesian methods to obtain seismic fragility models for electric power components. Stuart Werner and Craig Taylor presented issues arising when constructing seismic vulnerability models for transportation system components. Adam Rose dealt with the complex issue of validating models to estimate higher-order economic losses.

A persistent problem is how to develop prescriptive criteria that provide guidance and goals for acceptable risk procedures. In the previous monograph, Keith Porter reviewed and evaluated available life-safety criteria, and Daniel Alesch, Robert Nagy, and Craig Taylor addressed available financial criteria.

Inasmuch as technical procedures do not comprise the full scope of acceptable risk processes, three additional papers covered communication, administration, and regulation issues. From an owner's and then an engineer's perspective, Dick Wittkop and Bo Jensen addressed challenges in communicating risk results. Frank Lobedan, Thomas La Basco, and Kenny Ogunfunmi discussed the administration of the major wharf embankment and strengthening program at the Port of Oakland. And Martin Eskijian, Ronald Heffron, and Thomas Dahlgren discussed the regulatory process for designing and implementing the engineering standards for marine oil terminals in the state of California.

Synopses of Papers in Second Monograph

The first monograph covered many broad topics pertaining to acceptable risk processes for lifelines and natural hazards. However, in the early stages of development of the second monograph, it became clear that many important topics were in fact not treated. The first monograph's coverage focused on earthquake risks, a field that has shown quantitative sophistication for almost 40 years. In spite of remaining uncertainties in estimating earthquake risks, especially for spatially distributed infrastructure systems, the degree of quantitative sophistication for these risks is not matched by the number of other natural hazard risks. (See American Lifelines Alliance, 2002, section 3.0). Also, accidental and malicious threats were at best an afterthought to CDRM members until September 2001. In an effort to fill the apparent gaps, the second monograph covered broad topics including hazard issues, system evaluation issues, risk criteria issues, and systems management issues.

Under hazard issues, Steven Harmsen's paper extends the topic discussed by David Perkins in the previous monograph. Estimates based on probabilistic seismic hazard analyses (PHSA) are used in major seismic codes and have a significant bearing on many professional, governmental, engineering, and financial activities. Most importantly, PHSA-based estimates are used in risk studies, but often without sufficient regard to the uncertainty in these estimates. This paper illustrates the quantitative sophistication in developing inputs for estimates of earthquake hazard and risk and resulting uncertainties, and presages further quantitative development in seismic risk evaluation of infrastructure systems. For purposes of evaluating and expressing uncertainties resulting from diverse inputs source and attenuation models and assumptions, Harmsen, following USGS (Frankel et al. 2002), has developed a logic-tree formulation that represents the broadest features of the input alternative at every phase. Instead of accumulating exceedance probabilities at a fixed ground motion level, however, he computes ground motions at a fixed exceedance probability model. Harmen uses the input models and weights as found in the USGS 2002 national hazard mapping work. To supplement this USGS 2002 input information, he adds a preliminary representation of uncertainties in rates of occurrence from known faulting systems and an estimated range of uncertainty for areal source rate and b-values. Results of these logic-tree models are expressed, for instance, in terms of probability density functions of strong ground motion values for a specific return period. These findings can thus be used not only to guide future research but also to express more fully the range of uncertainties in earthquake hazard and risk evaluation as a result of its quantitative sophistication.

In "System Evaluation Issues," Jose Borrero, Sungbin Cho, James E. Moore II, and Costas Synoloakis discuss tsunamis and transportation system analysis and cover a multi-disciplinary project employing expertise in tsunami generation and run-up analysis, transportation system analysis, and higher order economic analysis. Beverly J. Adams and Charles K. Huyck cover how remote sensing can assist not only in pre-disaster planning but also in post-disaster planning as well. Dorothy Reed, Jane Preuss, and Jaewook Park focus on the electric power distribution system impacts of four major Pacific Northwest storms and also the 2002 Nisqually earthquake. This focus provides initial data for estimating outage times and also for assessing local vegetation management polices and practices.

Under system management issues, Mihail Popescu and Manoochehr Zoghi provide a comprehensive account of the state-of-the-art-practice in assessing, evaluating, and managing landslide risks. Yumei Wang and Amar Chaker probe the vulnerability to multiple natural hazards in the Pacific Northwest, a region with diverse geologic settings. The authors examine the complex relations among different modes of transportation (highways, rail lines, and river navigation) and geologic hazards, and assess their importance for the community and the regions. The study results indicate that geologic hazards in the Columbia River transportation corridor can have severe, long-lasting impacts on the economy of Oregon, affect productive capacity, and slow the pace of economic growth and development. Le Val Lund and Craig Davis use an historical approach to explain how the Los Angeles Department of Water and Power Water System has coped with all the natural hazards as well as with emergency preparedness and homeland security. Balancing these risk reduction activities and resources needed to effect specific risk-reduction objectives requires well defined but flexible plans of action.

Genesis of This Monograph and Expansion of Its Objectives

On October 26, 2005, the international activities were jointly sponsored by ASCE's International Activities Committee (IAC) and its Council on Disaster Risk Management (CDRM). The day started with a morning symposium, which covered a wide variety of issues from the recent flurry of hurricanes and how the internationally critical Port of Los Angeles addresses its major risk management issues to lessons learned from the December 26, 2004, earthquake and tsunami.

At the symposium, with Nasim Uddin and Craig Taylor as moderators, the following presentations were given:

- Mark Levitan, Ph.D., Louisiana State University, on risk reduction from hurricane and impact of Hurricane Katrina
- Constantine E. Synolakis and Jose Borrero, University of Southern California, on risk reduction from tsunami
- Stephanie King, Ph.D., Weidlinger Associates, on mitigation from terrorism
- Tony Gioiello, P.E., Chief Harbor Engineer, Port of Los Angeles, on mitigation measures by Port of Los Angeles
- Yumei Wang, P.E., M.ASCE, Sustainable Living Solutions and Oregon Department of Geology and Mineral Industries, on lessons learned from East Asia tsunamis

In addition, in a luncheon presentation, "Disaster Reduction for the Poor," Jelena Pantelic, senior operations officer of the Policy Support Unit Corporate Secretariat at The World Bank, discussed how natural disasters exert an enormous toll on development. In doing so, they pose a significant threat to prospects for achieving the Millennium Development Goals, in particular, the overarching target of halving extreme poverty by the year 2015. Annual economic losses associated with such disasters averaged US$75.5 billion in the 1960s, US$138.4 billion in the 1970s, US$213.9 billion in the 1980s, and US$659.9 billion in the 1990s. Most of these losses are concentrated in the developed world and fail to capture adequately the quantitative impact of the disaster on the poor, who often bear the greatest cost in terms of lives, livelihoods, and the rebuilding of their shattered communities and infrastructure.

Finally, in the international roundtable, "Surviving Nature's Forces: Have Civil Engineers Built Safe Communities?" panelists discussed issues relating to the fact that civil engineers are largely responsible for building the communities that are destroyed by the forces of nature. The roundtable explored some basic tenets of the future role of civil engineers in protecting human health, safety, and welfare. Accepting the challenge and joining the roundtable, a panel of experts raised provocative questions for the international engineering community. The responses and views in these presentations covered findings from evaluation teams who have traveled to the locations affected by the recent tsunami.

An Overview of Disaster Risk Assessment and Management Processes

Figure 1.1 provides a simplified outline of acceptable risk management procedures for threats to structures and facilities. In the case of natural hazards, risk is most meaningful when expressed in terms of potential human sufferings and/or economic losses. Besides the probability of a hazard occurring, risk must include the potential adverse consequences that can result from the hazard event. The risk associated with natural hazards—including strong earthquakes and associated tsunamis, high hurricanes (or typhoons), tornadoes, floods, and massive landslides—are very real. The forces created or induced by these natural hazards are usually extremely high and can cause severe damage and failures of engineered systems. Engineers, however, must still plan and design structures and infrastructures in spite of the extreme forces natural hazards produce. How safe infrastructure or facilities should be for resisting the forces of natural hazards, of course, depends on the capital investments stakeholders, such as the government entity responsible for funding, are willing to make for safety and reliability. Information on risk and associated risk reduction accruable from additional investment are clearly pertinent to making the proper decisions on needed or optimal investments. Again, this information would be most useful and effective if presented in quantitative terms.

The stakeholders must properly and thoroughly evaluate the risk or probability of a hazard event occurring in the performance designed facility. The basic questions they should ask are:

- What events are anticipated?
- What level of loss/damage/injury/death is acceptable?
- How often might this happen?

As they ask themselves these questions, and develop the variety of scenarios to which to apply them, the stakeholders must remember that obtaining consensus on acceptable levels of risk is essential to the successful outcome of the project.

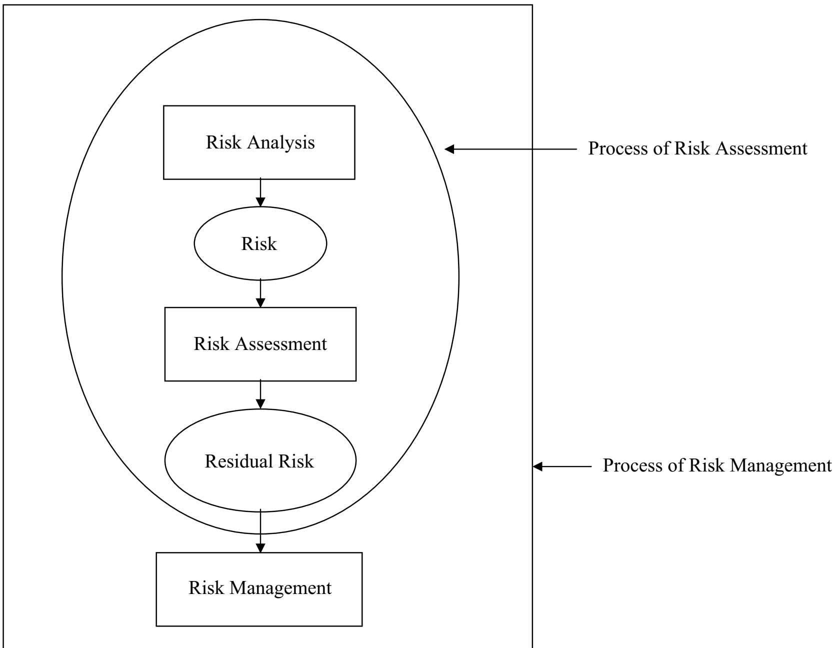

Figure 1.1. Simplified outline of acceptable risk management

Risk analysis incorporates the likelihood of a specific event and the severity of the outcome. This process combines both the severity and the probability of all relevant hazard loss scenarios. Remember that it is the intent of a performance-based code to establish the acceptable or tolerable level of risk. The overall analysis must consider not only the frequency of an event's occurrence, but also the effectiveness and reliability of the entire building as a system. Risk analysis provides a quantitative measure of the risk. It also can establish the basis for evaluating acceptable losses and selecting appropriate designs. Risk managers use two different evaluative methods in risk and hazard analysis: deterministic and probabilistic.

Deterministic analysis relies on the laws of physics and chemistry, or on correlations developed through experience or testing, to predict the outcome of a particular hazard scenario. In the deterministic approach, one or more possible designs can be developed that represent the worst possible credible events in a specific building. In this approach, the frequency of possible occurrences need not be evaluated.

Probabilistic analysis evaluates the statistical likelihood that a specific event will occur and what losses and consequences will result. In addition to using analysis techniques and experimental findings, this approach uses considerable statistics—including the incorporation of historical information.

Designers and owners of facilities in flood or high wind-prone regions need to begin to think in terms of a few basic objectives:

- Can the real probabilities and frequencies of events during the useful life of the structure be defined with a useful degree of accuracy?
- Can the extent and kinds of damage (if any) that can be tolerated be defined?
- Are there ways (if any) in which this acceptable level can be achieved?
- Are there alternative levels of performance that can be achieved, and how much do they cost over the lifetime/ownership of the structure?
- Are these levels below, at, or above design to code enforced criteria?

Brief Synopses of the Papers Included in This Monograph

The first two monographs covered many broad topics pertaining to acceptable risk processes for lifelines and natural hazards. The broad topics addressed were technical issues, risk criteria issues, communication, administration, and regulation issues. In the second monograph, the broad topics covered are hazard issues, system evaluation issues, risk criteria issues, and system management issues.

Some of the papers included in the second monograph cover significant technical features of integrated risk evaluations for natural disasters, whereas others deal with the complex personal, organizational, institutional, regulatory, and risk communication features of acceptable risk management. The following discussion begins with a review of the white paper on the overall responsibility of civil engineers in the context of disaster mitigation.

Role of Civil Engineers in Disaster Mitigation

A bigger question is if civil engineers are doing their job in mitigation or if the role should be redefined.

The recent devastating earthquakes, tsunami, and hurricanes resulted in an international human tragedy affecting more than a dozen countries. The white paper "Surviving Nature's Forces: Can Civil Engineers Build Safe Communities?" by Yumei Wang and Erik Vanmarcke, prompted by this human tragedy, considers that civil engineers were much involved in building the infrastructure of the communities that were destroyed. They question some basic tenets of the role of civil engineers: Have they built sufficiently safe communities, and are they adequately and responsibly protecting the public from natural disasters? Observing the scale of the tsunami disaster, it seems obvious that the status quo is not good enough. A better balance needs to be achieved between potential losses, in human and economic terms, from natural disasters and expenditures on infrastructure protection. Civil engineering professionals are the most knowledgeable and best positioned to play a leadership role in realizing this goal of optimally balanced risk. Do civil engineers need a new road map that maintains traditional strengths but redefines and amplifies their role? In this paper, the authors ask some questions, intended to provoke discussion at future international roundtable sessions, about how to protect our communities and, in this context, expand and improve the quality of services that civil engineers provide.

The discussion then continues with a review of the more technical papers and is followed by the review of the less technical papers.

Disaster Risk Assessment for Hazard Mitigation.

In his paper "Fundamentals of Quantitative Risk Assessment for Natural Hazard Mitigation," A. H-S. Ang describes key elements in integrated risk assessment and summarizes the fundamentals for the systematic and quantitative assessment of risk, with particular emphasis on hazard mitigation. In addition to the "best estimate" measure of a pertinent risk, the assessment of the uncertainty underlying the calculated risk is equally important. These are illustrated with a quantitative assessment of the risks for a 20-year period of a Category 4 hurricane occurring in New Orleans, assuming that the assessment was performed in 1990 (15 years prior to the occurrence of Katrina in 2005). This illustration shows that even a risk evaluation that is very simple compared to the more detailed evaluations that could be made with today's technologies could have been helpful.

The fundamentals of quantitative risk assessment (QRA), as presented in the paper, demonstrate that QRA is a valuable tool for engineers to generate quantitative technical information on risk and its associated uncertainty. A conservative (or risk averse) measure of risk may be specified to reduce the effect of the underlying (epistemic) uncertainty. Although it is the decision maker's role to select the risk-averse value, the risk analyst can and must specify the appropriate risk-averse values. QRA can also be used to assess the benefit in risk reduction accruable from an incremental investment, and thus provide a quantitative basis for benefit-cost study that may be essential and useful for making risk-informed optimal decisions.

Among all engineers, civil engineers in particular have the primary responsibility for the design and planning of civil infrastructure systems, including protective systems to minimize losses of lives and economies during extreme hazard events. In this light, there is every reason that civil engineers should be equipped with the tools of QRA, especially when dealing with problems involving natural hazards.

System Evaluation for Hazard Mitigation.

Another key feature is administration of an acceptable risk evaluation program. In the paper entitled "Port Of Los Angeles Risk Management Strategies," Tony Gioiello and Richard C. Wittkop outline how a major port has so far administered the very comprehensive acceptable risk evaluation of potential threats for ports.

In light of the port's importance to the local and national economy, the port has risk management strategies already in place. The port will also undertake the completion of a risk reduction plan to identify those facilities and systems that may be vulnerable to seismic or other events as well as ways to mitigate the port's risks in those areas. This approach is based on the premise that no matter what level of risk reduction is implemented, there is always some residual risk of damage; i.e., it is not possible to achieve zero risk. An acceptable risk is defined as the point at which the residual risks from an event remain acceptable and beyond which the costs to further reduce these risks are no longer affordable. This approach will (a) enable the Port of Los Angeles (POLA) decision-makers to weigh relative costs and residual risks associated with various candidate risk-reduction strategies, and (b) thereby, make a more informed selection of a preferred strategy that will reduce these residual risks to an acceptable level. Ultimately, individual organizations must decide how much of their resources they should expend to protect themselves, the public, and their assets against natural hazard and manmade events and how these resources should be utilized. Recognizing that all risk cannot be eliminated, the POLA's goal is to develop a strategy that minimizes risk but is affordable.

Reduce the Effects Caused by Hazards.

The previous monographs primarily focused on the prevention of infrastructure risks from natural hazards. Even with sound preventive measures, though, there remain residual risks that are sometime extremely large and grave. A natural hazard is an unexpected or uncontrollable natural event that usually results in widespread destruction of property or loss of life. In the paper "Surviving Natural Forces from Taiwanese Civil Engineers Perspective," Edward H. Wang, Hsieh Yuen Chang, and Ming-Hsi Hsu expand this discussion by offering perspectives on life-safety efforts in Taiwan.

The authors begin with a brief historical account of the effects of natural hazards and how additional hazards from industrialization have affected Taiwan. Located in a geographically unique place, Taiwan has suffered 6.6 significant natural hazard events— typhoons, earthquakes, floods—per year during the last decade. This paper introduces the types of natural hazards threatening Taiwan today and summarizes efforts by researchers and civil engineers to resist these natural forces. As members of the international community, Taiwanese civil engineers want to share their experience in natural hazard prevention and mitigation.

The environmental features of Taiwan—its location at the intersection of Eurasian and Philippine Sea plates as well as in the path of warm ocean currents—result in frequent natural catastrophes, tremendous casualties, and severe economic losses. Typhoons, earthquakes, and flooding are the major natural disasters threatening the Taiwanese people today. Because emergency response time is quite limited in Taiwan, emergency response teams must manage disaster efficiently. This article summarizes the overall efforts of civil engineers from various sectors in Taiwan to reduce the impact of natural hazards. There are numerous successful experiences and yet still room for improvement. Civil engineers in Taiwan continue to make their country a better place to live. In addition, the authors feel obligated to help the international community.

Lessons Learned from Recent Disasters

As unfortunate as these disasters were, they offer tremendous opportunities for the civil engineers to learn from previous short falls and ensure future public safety.

On December 26, 2004, a devastating earthquake occurred off the western coast of Sumatra, Indonesia, creating seismic and tsunami waves that were felt by people all around the Indian Ocean. The Sumatra-Andaman Islands earthquake was one of the largest earthquakes ever recorded with a moment magnitude of 9.1.

This earthquake triggered a destructive tsunami that affected many of the coastlines around the Indian Ocean. The most severe damage occurred in low-lying coastal regions of Indonesia, Thailand, Sri Lanka, and India. As days passed, the world was largely paralyzed by the unfolding disaster and the human toll, which was estimated at more than 250,000 deaths. The tsunami destroyed much of what lay in its path and resulted in an international human tragedy with the heaviest tsunami casualty loss in recorded history.

In the paper titled "Surviving Natural Disasters: Lessons Learned from the December 26, 2004 Sumatra Quake and Tsunami," Yumei Wang, Curt Edwards, Amar Bhogal, and Anat Ruangrassamee review investigation findings in coastal Thailand and discuss some of the lessons learned from this tragedy. Findings clearly indicate that structures and lifelines require sound engineering design and construction, including tsunami-resistant buildings (at least for more important structures). Additionally, tsunami education for communities and a regional tsunami warning system are needed.

Construction Challenges

The paper "Achievements and Challenges of China Construction," by Xila Liu proves the complex relations among construction and natural hazards, and assess their importance for the community and the region. China is at the starting point of an accelerated urbanization process. A great number of infrastructure projects and residences are under construction. China's construction achievements are briefly introduced, and its construction challenges are indicated frankly. Finally, as the key point for further development, measures on construction quality and safety are emphasized.

Political Commitment to Disaster Mitigation

Finally, there are many features of the acceptable risk processes and mitigation beyond the technically-oriented, integrated systems evaluation. One such key feature is risk communication to the policy-makers.

In the paper "Preparing for the Big One," Swaminathan Krishnan discusses the importance of constantly engaging governments in discussion to ensure that the quality of our infrastructure is maintained. Failure to do so could be catastrophic, as was witnessed in New Orleans when the storm surge from Hurricane Katrina (August 29, 2005) breached or overtopped the aging levees. Paradoxically, scientists and engineers at the Louisiana State University hurricane center had envisioned exactly such a scenario. Only three years earlier the local New Orleans daily newspaper, *The Times Picayune*, had published an article pointing out the danger to the levees and even identified the most vulnerable regions. In this case, the back-end effort studies had been conducted. The vulnerability of the infrastructure had been identified and even publicized through mass media. Yet, the government had cut almost in half funding in 2005 for the city's two main flood control programs, including the giant levees. This failure by scientists and engineers to implement the front end effectively cost the people of New Orleans dearly. Forcing political commitment to disaster mitigation requires keeping the channels of communication busy with a steady flow of information to educate the decision-makers. Therefore, the goal is to keep extreme events from becoming catastrophes, scientists and engineers have to become proactive. They should not only anticipate, estimate, and prepare at the back end, but also ensure that the correct solutions are implemented in a timely manner at the front end. Scientists and engineers should become better communicators and educators, and take a more active role in influencing their governments.

Selected Literature

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