School Earthquake and Tsunami Safety in APEC Economies: Reducing Risk and Improving Preparedness

APEC member economies shown in green

Edited by

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GHI's contributions to the October 2011 workshop and this report built upon earlier work with the Organisation for Economic Co-operation and Development (OECD). Mr. Richard Yelland and Ms. Hannah von Ahlefeld of OECD's Centre for Effective Learning Environments were key contributors to that *GHI-OECD School Earthquake Safety Policy Initiative* (2004 - 2008). GHI would like to acknowledge their role in developing an OECD draft school safety policy and questionnaire, which were adapted for this project to suit conditions within the APEC region.

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Part One: Project Overview

Introduction

In 2011, **GeoHazards International (GHI)** led a nine-month initiative to provide guidance to **Asia-Pacific Economic Cooperation (APEC)**—the leading forum for facilitating economic growth, cooperation, trade and investment in the Asia Pacific region—on how to keep children safe at school during natural hazard events.

APEC Member Economies

Without exception, countries of the Asia Pacific region share exposure to natural hazards associated with their location along the "Ring of Fire," an arc that stretches from New Zealand, along the eastern edge of Asia, north across the Aleutian Islands of Alaska, and south along the coast of North and South America. The Ring of Fire is home to over 75% of the world's active and dormant volcanoes. Close to 90% of the world's largest earthquakes occur along its length. In addition, the Asia Pacific region confronts pyroclastic and debris flows from steep volcanoes, landslide, rock fall and tsunami hazards, as well as hydrometereological hazards such as droughts, floods, typhoons and forest fires. The magnitude and frequency of these hazards present serious challenges to safety, welfare and long-term development throughout the region.

GHI worked with representatives of APEC's 21 member economies[1] to develop a comprehensive school safety framework tailored to the conditions in APEC economies. These include natural hazard and vulnerability profiles, school governance structures and more. The growth and future prosperity of APEC economies rely upon children's access to education. More fundamentally, students everywhere have a right to learn in schools that are safe from and prepared for natural hazards. An effective school safety policy can help communities to develop, unimpeded by setbacks from natural hazard events.

Major Earthquakes in the APEC Region, 2004-2011

Location	Date	Magnitude
Japan	3/1/11	8.9
New Zealand	2/22/11	6.3
China	4/14/10	7.1
Chile	2/27/10	8.8
Indonesia	9/30/09	7.6
Japan	8/9/09	7.1
New Zealand	7/15/09	7.6
China	5/12/08	7.8
Peru	8/15/07	8.0
Japan	7/16/07	6.8
Indonesia	3/28/05	8.7
Indonesia	12/26/04	9.1

The centrepiece of the *School Earthquake and Tsunami Safety in APEC Economies: Reducing Risks and Improving Preparedness* initiative was a three-day workshop held in October 2011 in Chinese Taipei. Here representatives of APEC economies were able to exchange relevant knowledge and experience, discuss best practices, and review and advise regarding GHI's discussion draft of an APEC school safety policy framework. This workshop was sponsored by the United States, Chinese Taipei, Peru, Australia and New Zealand. The United States Department of State and the United States Geological Survey served as project overseers. The National Science & Technology Center for Disaster Reduction (NCRM) of Chinese Taipei provided essential local support.

Safe@ School—Protecting Children from Natural Hazards

Safe@ School—Protecting Children from Natural Hazards, the school safety framework that emerged from the workshop, identifies new opportunities for APEC to exercise leadership in promoting school safety in natural hazard events. The framework's principles and activities can significantly increase resilience and reduce risk among APEC economies. *Safe@ School* acknowledges and incorporates key conclusions from the APEC Emergency Preparedness Working Group (EPWG)'s September 2009 Hanoi report *Disaster Risk Education at Schools.* It also leverages principles and elements that

1 Australia; Brunei Darussalam; Canada; Chile; People's Republic of China; Hong Kong, China; Indonesia; Japan; Republic of Korea; Malaysia; Mexico; New Zealand; Papua New Guinea; Peru; The Republic of the Philippines; The Russian Federation; Singapore; Chinese Taipei; Thailand; United States of America; Viet Nam.

GHI developed through its multi-year School Earthquake Safety Policy Initiative with the Organization for Economic Development and Cooperation (OECD)[2], which produced the *OECD Recommendation Concerning Guidelines on Earthquake Safety in Schools*.

In addition to the *Safe@School* framework endorsed by workshop participants, this report will provide GHI's recommendations on next steps for APEC to build the capacity needed to reduce risk in schools. Recognizing the capability of APEC's Education Network (EDNET) and its interest in school safety, the recommendations will propose future collaborative capacity-building project(s) with EDNET. They will propose that each economy's government adopt and implement the *Safe@ School—Protecting Children from Natural Hazards* framework for the safety of children at school during natural hazard events, and that a specific agency, at either the national or the subnational level, have the expertise and commitment required to monitor and report on progress toward these goals. They will propose that a follow-on workshop be held in 2013, at which participating economies can report on progress against benchmarks in strengthening the resilience of their populations and infrastructure from natural hazards.

Private Sector Engagement

At the APEC Economic Leaders' Meeting in November 2011, one month after the GHI-led school safety workshop in Chinese Taipei, leaders pledged to increase private sector engagement in disaster resilience. This pledge is in keeping with APEC's "whole society approach," advocated in the (2010) *Public-Private Partnerships and Disaster Resilience* workshop report, which noted that

> The private sector has proven that it can and does play a fundamental role in building the resilience of a society against potential impacts from disasters. It can provide resources, expertise, and essential services. In many economies, critical infrastructure on which a society depends is operated by the private sector.

In this report, GHI will recommend that APEC encourage corporations to support *Safe@School—Protecting Children from Natural Hazards* activities, as ideal objects of Corporate Social Responsibility community service campaigns. GHI will describe its own pioneering collaborations with industry leaders like Bechtel Group Foundation to reduce risk and raise awareness of natural hazards and will profile one school preparedness program in detail (See "Corporate Social Responsibility in Disaster Risk Mitigation" in the Background Information section).

Implementation Plan

APEC is well-suited to assist member economies with their efforts to reduce the risk to schools from natural hazard events: APEC members represent many of the world's most vulnerable areas with regard to earthquakes, tsunamis, volcanic events and other hazards. While risks are held in common, knowledge resources vary greatly between economies;

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[2] OECD and APEC have in common the following members: Australia, Canada, Chile, Japan, Mexico, New Zealand and the United States.

this makes risk reduction demonstration and capacity building projects within APEC particularly worthwhile. APEC members have an impressive knowledge base, with many of the world's most experienced and knowledgeable academicians and practitioners living and working in APEC economies; as yet, however, other members have been isolated from this knowledge. APEC has an opportunity to provide a collaborative forum for members to diffuse knowledge and guide and encourage risk reduction and preparedness measures that the private sector and governments can undertake. APEC can promote the safety of children in schools, strengthen member economies against the human and economic threats of natural hazards, and promote inter- and extramural business opportunities.

Earthquakes and natural hazards are ideal focuses for collaboration. They threaten all varieties of human settlement: urban and rural, wealthy and poor. Working together to address the resulting risk increases economies' safety, stability and capacity for economic and cultural growth. Improved understanding of natural hazards and of engineering techniques to build properly and to manage risk strengthens the foundation for business activities within the region. Cooperative projects allow people from disparate cultures to work towards a common good, against a common threat. Each economy and business has its unique set of values, hazards and priorities; still, all benefit from collaboration.

APEC has an opportunity to promote "earthquake diplomacy" via cooperative and unilateral projects of its member economies. Natural hazard diplomacy also offers opportunities for socially responsible private companies to help their communities reduce risk from natural hazard events. Corporations can support successful, reasonably sized risk reduction projects in the communities where their workers, suppliers and/or customers live. Their support for school safety programs pays dividends in terms of improved life quality and safety of those served, increased pride of employees who witness their employer's generosity and wisdom, improved community relations and even good public relations.

Elements of Successful Risk Reduction Programs

Successful programs to reduce risk from all natural hazards and to improve the resilience of communities share the following key elements:

- Hazard identification and assessment
- Knowledge acquisition (education and awareness)
- Warning of impending hazard conditions
- Proper location, design and construction of buildings

Teachers are an often-untapped resource for collecting vulnerability information and for delivering information and preparedness lessons to the entire community.

"All Hazards Approach"

GHI and workshop attendees strongly recommend that APEC economies adopt an "all hazards approach" as the best way to save lives and money: in this approach, monitoring and warning systems are designed to alert and inform at-risk populations about all major hazards in their area, to the extent possible.

While many natural hazards can threaten life, health and property, the 2011 workshop concentrated on the need to prepare for rapid-onset natural hazards (such as earthquakes, near-shore tsunamis, volcanic flows—lahars, debris avalanches and pyroclastic flows—rock falls, landslides and mudflows), which strike without warning.

Communities at risk from other hazards that strike slowly or with warning (such as wildfires, wind and storm surges from cyclones or typhoons, river flooding, tele-tsunamis, volcanic eruptions and ash falls) should address those hazards as well.

Overall Recommendation

Participants in the project workshop agreed that because school children have a right to learn in buildings that are safe from natural hazard events, and because access to education is a vital economic driver, APEC should recommend that economies increase children's safety through:

(a) Implementing the *Safe@School—Protecting Children from Natural Hazards* framework endorsed by the October 2011 EPWG workshop (see page 9); and
(b) Approving capacity-building projects conducted by the EPWG, in cooperation with EDNET.

Implementation Plan Recommendations

The following recommendations outline specific implementation strategies that APEC could pursue, in order to demonstrate leadership on the issue of school safety in natural hazard events, thereby building the resilience of member economies and making children more secure:

1. EPWG should forward the consensus policy framework developed at the workshop to APEC ministers and leaders, encouraging these bodies to increase the visibility of school safety within APEC, given its relation to economic progress and humanitarian values. Specifically, the EPWG should seek endorsement of the overall recommendation that APEC economies ensure children's safety through implementing *Safe@School—Protecting Children from Natural Hazards* activities via other working groups, APEC ministers and leaders;

2. EPWG should publicize the results of the October 2011 workshop within APEC member economies and should encourage the economies to adopt the policy framework and to use the assessment protocol, background information and case studies provided in this report;

3. APEC, represented by its EPWG and EDNET, should offer demonstration projects and collaborative capacity-building efforts for those responsible for schools, at the

request of interested member economies. Projects should engage persons responsible for school safety within education ministries and at subnational levels, where appropriate. Capacity building should address all areas (hazard identification, design, evaluation, preparedness, and curriculum). Initially, two pilot projects could demonstrate the benefits and develop the techniques for use on a wider scale;

4. APEC should promote school safety during natural hazards as a Corporate Social Responsibility (CSR) measure, providing examples of school safety and preparedness work sponsored by the Bechtel Group Foundation. The accomplishments of participating corporations should be publicized, to send the message that individual businesses can make a difference and to incentivize other corporations to support similar efforts; and

5. EPWG should sponsor a workshop in 2013 to assess progress made in improving the safety of children at school in APEC economies.

The *Safe@School—Protecting Children from Natural Hazards* Framework

(Endorsed by participants in the October 2011 workshop, "School Earthquake and Tsunami Safety in APEC Economies: Reducing Risks and Improving Preparedness.")

Principles

The Workshop participants propose that APEC encourage every economy to adopt and implement a policy that enshrines the following principles:

A. Every child has a right to attend school in safe buildings.

B. Governments and education leaders are responsible to mobilize efforts to ensure the safety of schoolchildren from natural hazards. This requires a strong commitment to sustained action: implementing an effective school safety program is a long-term undertaking.

C. To fulfill their responsibility to ensure the safety of schoolchildren, governments and education leaders must

1. Identify responsible agencies and officials in the government and private sectors;
2. Define expectations regarding their roles in a school safety program;
3. Identify funding sources for their work;
4. Identify hazard areas and vulnerable buildings;
5. Identify necessary education and preparedness activities;
6. Measure progress on reducing risk;
7. Report to higher authorities, parents and teachers on items 4, 5 and 6.

D. An effective school safety program will

1. Stipulate the desired safety performance for school buildings and construct all new schools to meet this standard;
2. Educate students on natural hazards and risk reduction measures;
3. Provide preparedness training;
4. Review conditions of all existing school buildings and retrofit, relocate or replace unacceptably vulnerable buildings;
5. Draft and enact plans for post-event continuity of education services.

Activities

Activities are programs or practices that carry out the principles embodied in the policy statement. They are the essential ingredients of an effort to ensure student safety during hazard events.

1. **Identify and map hazards nationwide and in detail at every school site** in order to define the frequency and intensity of natural hazards and the level of potential impacts on students and schools. Consult the hazard maps before constructing new buildings or expanding existing buildings, and incorporate measures into building design, preparedness efforts, and risk reduction programs to reduce the hazard threat;

2. **Prepare a long-term risk reduction plan** that identifies school buildings that do not meet performance standards because of structural weakness or site-specific hazards, and implement the risk reduction plan by retrofitting, replacing or relocating dangerous school buildings;

3. **Identify an organization to implement or oversee the plan** and its elements. This organization would:
   a. Identify those responsible for every activity, measure their performance and report results;
   b. Approve the location of new schools with regards to natural hazards;
   c. Review construction drawings for compliance with building codes;
   d. Inspect construction to ensure that builders follow the approved plans and specifications;
   e. Approve evaluations of existing school buildings and locations, and keep records on the condition of deficient buildings.

4. **Adopt and enforce a building code** that includes stringent building standards and enforcement requirements for school buildings;

5. **Establish standards for professional practice and provide a training program** to ensure that the professionals who analyze potential sites and who design and construct school facilities are properly qualified;

6. **Conduct a preparedness program in every school** to ensure that emergency and evacuation plans are prepared with consideration of the hazard conditions of each school, that training sessions and exercises are held regularly, and that
   a. Warning and communications systems are in place and maintained to enable communication before and during emergency situations, and warnings of impending hazards (aftershocks, tsunamis, floods, debris flows) are transmitted effectively and on time;
   b. Building furnishings, equipment, contents and decorative building elements that can fall on students or impede evacuation are properly anchored;
   c. Community awareness campaigns engage families and the community in risk reduction and preparedness activities (This is a critical complement to school-based programs, as children are in school only 25% of the time.);

7. **Ensure that the curriculum followed in schools educates students** on natural hazards and measures to prepare and respond to hazard events;

8. **Appoint independent advisory committees** to provide expert advice on implementation and to provide oversight on the quality and the consistency of risk reduction efforts.

Conclusion

Since 1992, when ministers from fourteen member economies agreed to coordinate their joint education activities, APEC has worked to strengthen and promote the role of education in advancing sustainable socio-economic development. Each APEC economy mandates that school-aged children receive formal instruction, and each economy sets curriculum standards.

Yet natural hazards such as earthquakes, tsunamis and volcanic events can disrupt this careful planning in an instant, damaging school facilities, interrupting or ending the education of too many students, while harming or killing others. Such disruptions and losses have severe, long-term effects on communities and on the economy.

Every APEC economy has expressed concern for the safety of children at school. And indeed, recent catastrophes in the region—the 2004 Indian Ocean Tsunami, the 2008 earthquake in China's Sichuan province, the 2010 earthquake in Chile, and the 2011 earthquakes in New Zealand and Japan—drive home the importance of reducing risk and improving preparedness.

The Emergency Preparedness Working Group (EPWG)-sponsored project, *School Earthquake and Tsunami Safety in APEC Economies*, was initiated in 2011 to describe a comprehensive program to address natural hazards in schools and to recommend follow-on actions for APEC to consider.

The project issued a comprehensive questionnaire to participants that would help them to characterize existing school safety programs in their economies. Ten economies completed the questionnaire; all reported having exposure to multiple natural hazards. Respondents described the programs now in place in their economies to manage the risk from earthquakes, volcanic events and tsunamis. These responses provided a clear starting point for developing the draft ***Safe@ School*** policy framework.

At the three-day workshop held in October 2011 in Chinese Taipei, representatives of participating economies were able to hear from experts, view local earthquake safety efforts firsthand and discuss a school safety framework to guide all APEC economies. The participants considered a framework and endorsed an implementation plan, ***Safe@ School—Protecting Children from Natural Hazards,*** for consideration and use by APEC economies. Participants affirmed that every child has a right to attend school in safe buildings and that government and education leaders are responsible to mobilize efforts to ensure the safety of school children from natural hazards.

APEC has a significant opportunity to lead member economies by encouraging collaboration, holding workshops to build capacity, and seeking approval from ministers and leaders to establish ***Safe@ School—Protecting Children from Natural Hazards*** as APEC's recommended framework.

Part Two: Papers on Hazard, Risk, Vulnerability and Preparedness

GHI engaged subject matter experts to present detailed contextual reports at the October 2011 workshop in Chinese Taipei on topics that included:

- Earthquake, tsunami and volcanic hazards affecting APEC economies;
- Physical and organizational characteristics of school buildings that cause them to be vulnerable to damage and collapse;
- Common underlying factors that help to produce or leave in place unsafe school buildings;
- Select school safety policies and programs that have effectively reduced risk;
- Corporate Social Responsibility (CSR) initiatives that have promoted school safety from natural hazards.

The written reports, which follow, were supplemented by workshop presentations led by participating experts on educating students on natural disaster preparedness (Chinese Taipei), addressing school safety in the province of British Columbia (Canada), recovering from the Darfield and Christchurch earthquakes (New Zealand), tsunami preparedness programs and resources (United States and Indonesia), APEC's Education Network (EDNET), a Swiss Reinsurance Company Ltd.-sponsored school retrofit project (Peru), and emergency management communications and education programs (Australia).

These reports and presentations conveyed essential background information to participants seeking appropriate, efficient ways to reduce risk in schools and to prevent future setbacks to their communities from natural hazard events.

Keeping Students Out of Harm's Way: School Safety in Earthquake, Tsunami and Volcano Zones

Arrietta Chakos, Consultant to GeoHazards International

Over the last decade, natural hazards—earthquakes, tsunamis and volcanic activity—struck APEC economies frequently, with devastating effects on children and schools. The damage resulting from these natural hazard events disrupted education and diminished opportunities greatly needed by future generations and for economic growth. Yet recent events also demonstrated that comprehensive policies consistently carried out over time could significantly reduce the destructive consequences of future events. This paper examines how school safety initiatives have been conducted internationally and within the United States, in order to draw lessons on how risk mitigation can be effectively implemented and sustained. The level of risk from natural hazards in APEC economies is dauntingly high, as both recent catastrophes and loss projections for potential future events make clear. These sobering forecasts present a major challenge to the national governments and communities that must protect the public's well-being, in particular the well-being of the most vulnerable: seniors, economically deprived people and children.

FIGURE 1: EERI RECONNAISSANCE TEAM DON BOSCO HIGH SCHOOL, PADANG 2009. Image credit: EERI RECONNAISSANCE TEAM

Typically, tragic deaths in earthquakes happen when current engineering technology is not used and existing safety laws are not adequately enforced. Making sure that educational facilities and systems can withstand significant disruptions and safeguard the lives of children is a responsibility of communities and their governments. Children in at-risk regions are endangered when they are obliged to attend school in facilities which are vulnerable to hazards; prone to collapse due to poorly conceived design and seismically-inadequate construction; or in danger of being swept away by tsunamis, because of their location at low elevations close to the ocean.

In most of the world's economies, students are required to attend school. Because children are both vulnerable and valued by societies and their families, it is appropriate for those in positions of authority to provide educational facilities that safeguard students' well-being and safety. However, not all governments assume this responsibility. National and community leaders must take this initial step of becoming accountable for school safety to the parents of students to spark governmental action and partnership.

Because schools also often serve as community centers and emergency shelters, it makes social and economic sense to ensure these facilities are able to withstand disaster forces and to function as safe havens, after disruptive events. In many regions where schools are the focus of safety improvement programs, a parallel renewing effort occurs: public sector improvements prompt the private sector to undertake similar redevelopment efforts. This synergistic effect has been seen in areas where ongoing safety programs are in place, such as Northern California's San Francisco Bay Area, and in restoration efforts in disaster-stricken communities, such as New Orleans after the 2004 Hurricane Katrina.

FIGURE 2: PADANG MAG. 7.6 SEPTEMBER 30 2009 BY TIM HART
Image credit: EERI RECONNAISSANCE TEAM

Academic and technical experts agree that safety improvements that increase structural and disaster resilience can be accomplished at a reasonable cost, both in newly built and in renovated schools. Building costs, available materials and levels of technical knowledge each impact the practicability of earthquake-resistant construction in hazard-affected economies; officials must prudently balance these operational factors, as they strive to reduce risk in schools and to prevent future deaths and injuries.

Monitoring the status of school safety or the nature and number of human losses suffered specifically in school buildings is presently difficult to do. This is both a humanitarian and a public policy failing. Particularly in geologically active areas, government, education and community authorities need to have solid data about deaths and injuries in school buildings damaged by geologic hazard events. They can then better assess the vulnerability of their schools, in order to develop actions that will protect students and reduce risk.

School safety policies are not typically a subject of public interest or discussion, except in the immediate aftermath of a catastrophic event during which children died. Even then, public leaders and nations have not always acted to significantly reduce the physical risk to children who attend schools in geologically vulnerable regions. Catastrophic earthquakes and tsunamis cause such complex damage and social disruption that the need for communities to better understand and prepare for the unexpected has recently become a more active policy interest of local governments and some international institutions.

Transnational institutions such as the United Nations Development Programme, the Organisation for Economic Co-operation and Development (OECD) and the World Bank have launched ambitious risk assessment and reduction initiatives. Successful government managers have shared their experiences about how they study potential hazards, develop policies to address required renovations of unsafe structures, implement readiness programs and analyze the effectiveness of their efforts. Hazard-prone regions in the United States have demonstrated that incremental, but effective, safety improvements are possible. The examples provided in this paper suggest that even in fiscally challenging times, school safety can be accomplished.

An International Framework for School Seismic Safety

OECD is a multi-national institution that was originally founded to manage post-World War II Marshall Plan funds for the reconstruction of Europe. It has come to serve as a forum for its thirty-four member nations and as a platform for economic and development coordination. In 2004, GeoHazards International (GHI) and OECD convened seismic safety experts from many nations to develop school safety recommendations for OECD nations with earthquake risk. The impetus was the death of students in schools damaged or destroyed by earthquakes in Molise, Italy (2002) and Boumerdes, Algeria (2003).

OECD's governing body reviewed and debated the school safety guidelines and adopted the framework in 2005; at that time, the protocol was disseminated to OECD members and to other seismically active nations. The OECD program elements address seismic safety policy, including official and community accountability, building codes and code enforcement, training and qualification, preparedness and planning, community awareness and participation and risk reduction for new and existing facilities. They outline well-defined principles and articulate clear objectives for school seismic safety, defining the level of hazard to be addressed and objectives for school building resistance, giving priority to replacing unsafe schools and making new schools safe, establishing school safety as a long-term undertaking that calls for a multi-hazard approach, and calling for advisory committees to monitor implementation.

The OECD nations considered the expert recommendations included in the protocol and refined the policy and approaches to reducing earthquake risks for schoolchildren in at-risk areas. Participating countries suggested that governments in earthquake-prone countries act to prevent human losses and implement improved school design and construction. Via the OECD peer review process, governments can confer on how to develop and enact policies for improved seismic safety. This international protocol is a practical guide and model public policy adaptable for ready use. The OECD has developed a useful primer on the process and implementation of a model national safety program. GHI provided participants in the *School Earthquake and Tsunami Safety in APEC Economies: Reducing Risks and Improving Preparedness* workshop a copy of the OECD book, Keeping Schools Safe in Earthquakes (2004).

FIGURE 3: ISHINOMAKI CITY REMAINS OF BURNED OUT SCHOOL, AFTER MARCH 2011 TOHOKU EARTHQUAKE AND TSUNAMI. Image credit: EERI RECONNAISSANCE TEAM

School Safety Practice in the United States

The United States application of school safety policies offers one example of how a nation can systematically improve risky conditions. Public school building safety is primarily a responsibility of the local and state governments in the United States, with the federal government providing technical guidance and policy support. As is true for many disaster-prone nations, the United States has had mixed success with implementing comprehensive safety initiatives, especially ones that strove to reduce risk in older school buildings, which are often more structurally fragile than newer ones. The most prevalent problem in seismically active regions in the United States is how to address community safety responsibly, when the majority of existing buildings may be seismically vulnerable. In citing the policy issues that Americans must address about safe school facilities, the Western States Seismic Policy Council, a respected policy group, states:

> *"Every community is required to educate children, and it is the responsibility of governmental agencies to design and construct safe buildings to house them. While current building codes and construction practices have recognized the effects of earthquakes and provide state-of-the-art design considerations, many older school buildings were built before these principles were understood.*
>
> *Additionally, many existing buildings are constructed of materials such as unreinforced masonry, which are not in common use today due to their poor performance in past earthquakes throughout the world. These older buildings have not been properly graded or passed the test of seismic safety. Consequently, many students face significant seismic risk."*
>
> -The Western States Seismic Policy Council, June 2010

The United States federal government plays a supporting role in relation to state governments on school facility and physical safety matters. American federal law is silent on the matter of school building safety; state and local governments are responsible for education programs, as well as school facilities and infrastructure. There are federal departments and agencies that play a strong role in supporting the development of policies to affect safety guidelines for states and public school district authorities. (Private schools must also be considered in safety initiatives.)

The United States Department of Education directs overall federal educational program policy. Federal education officials guide academic and educational curriculum policy and work to ensure equal access to learning for all students. Through its Policy and Technical Analysis Support Office, the department's website states, the office "…coordinates policy and technical analyses; …implements cross-cutting analytic special projects…and supports the sharing of information on effective policies and practices." It serves as the major point of contact for coordinating projects and activities with Asia-Pacific Economic Cooperation (APEC) initiatives. The education experts recognize the need for safe schools and promote active efforts with partner federal agencies that address policies to promote physically safe and structurally resilient facilities.

The National Earthquake Hazard Reduction Program (NEHRP) provides technical assistance and guidance to school authorities on seismic safety. The National Institute of Standards and Technology (NIST), Federal Emergency Management Agency (FEMA) and United States Geological Survey (USGS) prepare and disseminate seismic risk information through engineering guidelines and hazards maps that delineate potential seismic dangers to at-risk regions in the United States The risk areas are prioritized by the extent of the potential earthquake hazards, and color-coded according to level of possible danger in widely distributed public information materials. The Applied Technology Council (ATC) and the National Institute of Building Sciences (NIBS), with support from FEMA, provide engineering guidance and draft code standards. NIBS also maintains the National Clearing House for Educational Facilities. Further, the agencies provide direction on how state and local school authorities can address safety improvements called for according to the regional risk. States use the structural evaluation methods developed by the NEHRP program and published by American Society of Civil Engineering (ASCE).

The federal government encourages emergency planning and mitigation in all sectors of the United States, and the Federal Emergency Management Agency provides limited funding through competitively awarded grants to local school districts for physical improvements through the Hazard Mitigation Grant Programs (authorized through the Stafford Act) and the Pre-Disaster Mitigation program (authorized through the Disaster Mitigation Act 2000). The federal grants usually leverage state or local funds to pay for safety upgrades and modernization improvements. State and local education officials look to the federal agencies to focus the development of consistent national policies for application in school districts. This policy direction from the federal government provides a framework for state and district officials to use when identifying risk issues and crafting solutions that work at the local level.

Safety policies and practices vary by state, because the hazards vary from state to state and because it is up to the states to decide what they believe is proper. The federal government can offer some incentives or can withhold federal resources to coax states or school administrators, but it cannot require the enforcement of building standards. The broader federal initiatives apply regional and local variations that are appropriate to the hazards at hand. (It is important to note that the school district governance structure may be unique to nations like the United States, while other countries may have national systems, no specific system, or a mixture of government and private schools, with the latter independent of government controls.)

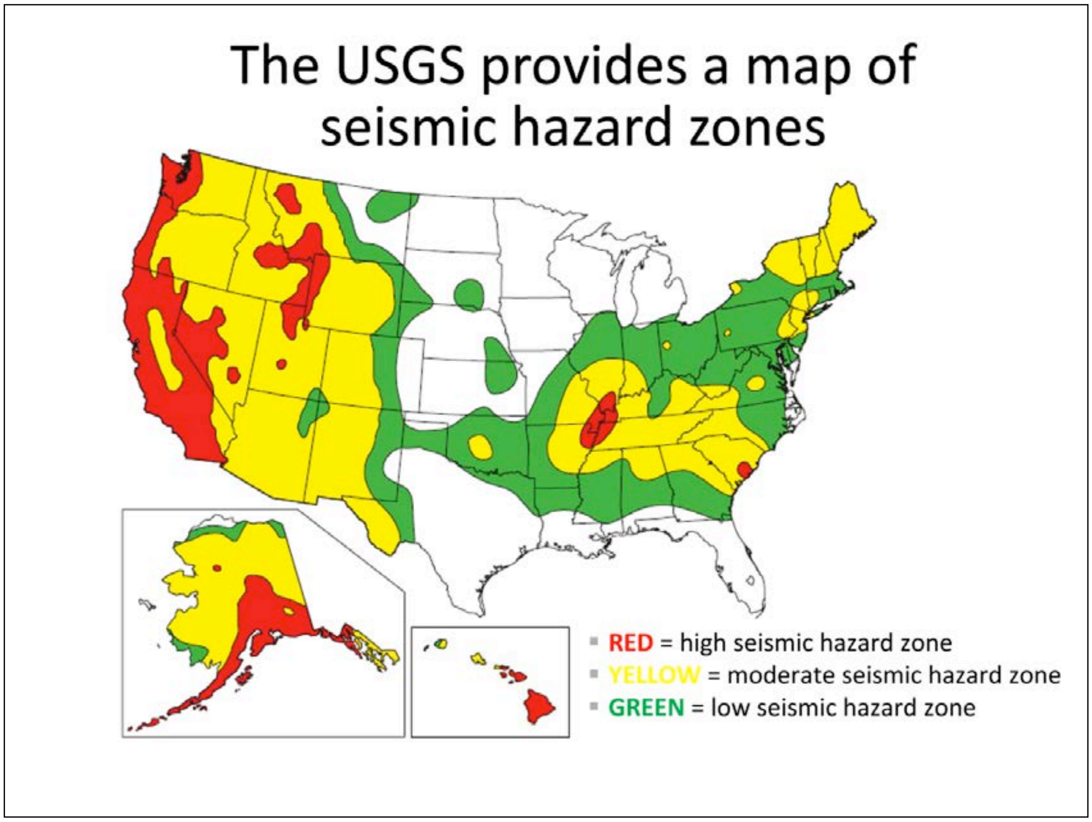

FIGURE 4: USGS SEISMIC HAZARD ZONES

States Implement Safety Efforts

By examining select practices that risk-vulnerable states in United States have developed through their policies and programs, one can learn how to make schools safer from earthquakes, tsunamis and volcanic activity. While strategies vary depending on the identified geologic risk to an area, states have approached their safety needs with some consistency through the legislative process and subsequent application of risk reduction measures at the community level. Most safety initiatives in the United States have been spurred by disasters with significant life loss that sparked public policy innovation and practical action.

Framing Events

Framing events that launch policy action are often triggered by specific disasters or prompted by proactive thinking on the part of legislators or community leaders. This paper provides examples from select regions that illustrate how major geologic hazard events are often followed by social and political actions intended to limit future losses.

California—The 1933 Long Beach Earthquake destroyed more than 200 school buildings, mostly of unreinforced masonry construction. The damage was so severe that the California legislature passed the Field Act within a month after the earthquake. That legislation stipulated:

> *"Public school buildings, constructed at public expense, were among the most seriously damaged buildings. Much of the loss and damage could have been avoided if the buildings and other structures had been properly constructed. The school buildings which will be erected, constructed and reconstructed to replace the buildings damaged or destroyed by the earthquake, shall be constructed to resist, in so far as possible, future earthquakes." (Chapter 39, Statutes 1933)*

The state of California's landmark effort in earthquake risk mitigation stemmed, in part, from the innovative mitigation approach that the Field Act outlined to achieve seismically safe schools. In response to this law and similar laws that address collapse-risk in schools built before the Field Act, much preventative action was undertaken over the subsequent decades, requiring school districts to replace or retrofit vulnerable schools and to build new earthquake resistant schools.

Oregon—After the 1989 Loma Prieta earthquake struck California, the Oregon State Senate created the Oregon Seismic Safety Policy Advisory Commission to analyze Oregon's seismic safety risks and to raise awareness about earthquake hazards through education, research, mitigation and legislation. This effort prompted numerous risk studies and engineering evaluations of schools and led to voter-approved funding for safety programs.

FIGURE 5: SCHOOL IN CHINESE TAIPEI DAMAGES ON THE COLUMNS OF HALLWAYS M6.2 TAIWAN MARCH 4, 2010 Image credit: EERI RECONNAISSANCE TEAM

Washington—The 1949 M 7.1 Puget Sound earthquake drove new seismic safety legislation in Washington State, in response. Puget Sound area schools were damaged, and two children died in the event. In Seattle, 12 schools were damaged, with three destroyed beyond repair. The Washington State Legislature responded by mandating that school facilities meet safety criteria in building codes adopted for new construction, which represented a noteworthy improvement over previous practice.

FIGURE 6: SCHOOL IN CHINESE TAIPEI DAMAGES ON THE COLUMNS OF HALLWAY (2) M6.2 TAIWAN MARCH 4, 2010
Image credit: EERI RECONNAISSANCE TEAM

Hawaii—After a devastating 1960 tsunami, authorities drafted a post-event plan for the coastal Hilo area to designate lands within the affected project area for uses that would reduce the danger and loss of life or property damage in tsunami-prone areas. This was the start of the state's forward-thinking tsunami safety initiatives.

Safety Practices in Disaster-Prone States

The states that have programs in place to address geologically induced disasters share experiences that served as catalysts for new attention to and public policy regarding hazards. The most established programs (in California, Oregon, Washington, Utah and Hawaii) have measures in place to address safety readiness in schools: these include preparedness initiatives, building safety laws, education programs and awareness efforts. These states lead the nation in seismic safety mitigation, and their work is illustrative of how technical research and policies can provide a foundation for sound public policy.

California school systems have safety programs that include training on fire safety, emergency response plans, evacuation plans, recovery plans, preparedness training and drills for students, faculty and administrators. In other areas of the country, safety programs address regional natural risks such as flooding or tornado safety. All states provide some amount of safety training for students and teachers, as called for by federal guidelines. Though the responsibility to ensure implementation lies with the local school officials, the general approach to plan development is shaped by United States federal guidance and dissemination of model templates and descriptive procedures for states and schools to use. The federal guidance on preparedness, shaped in response to the 9/11 terrorist attacks of 2001 and public health emergencies, focuses on response and rescue/relief efforts, rather than on pre-disaster mitigation of building risk.

States and local jurisdictions address building safety in a variety of ways. Many adopt the International Building Code to incorporate seismic safety standards in new school construction; some states address the need for safety upgrades in existing schools, when feasible, in their renovation and modernization programs. Collapse prevention and damage control are the performance objectives commonly expected, but not definitively assured by the building code. School building standards generally vary according to the levels of hazard in the individual regions. The Field Act provides that California's Division of the State Architect require compliance with the California Building Code, which is comprised of the International Building Code and California-specific enhancements. In seismically active California areas, higher than usual performance standards are in place, because of the potential for serious seismic damage.

The enforcement of building code standards is not consistent throughout the nation. Because there is little documentation on building code enforcement, it is difficult to ascertain how effectively seismic safety laws and regulations are being applied and to measure the efficacy of building standards in practice.

Preparedness Measures

The states featured here have well conceived preparedness programs that are used throughout the school year as teaching and training events. The most prominent of these is the "ShakeOut" program started in Los Angeles and now exercised in Washington, Oregon, and throughout California. The program's aim is to focus a region or state on an annual drill for millions of participants to test their earthquake readiness skills.

FIGURE 7: BAJA CALIFORNIA EL MAYOR CUCAPAH EARTHQUAKE APRIL 2010 CALEXICO PUBLIC SCHOOL FALLEN LIGHT FIXTURES Image credit: EERI RECONNAISSANCE TEAM

The state departments of education require schools to post evacuation maps; schedule practice sessions for fire, earthquake, lockdown, shelter-in-place, and other situations, as safety officials deem necessary. Fire drills are required quarterly for elementary and secondary schools, but compliance enforcement is uneven, and there often is little oversight; earthquake drills are also required. State education agencies and local districts rely on federal information and guidance in the formulation of these efforts. FEMA and the National Clearinghouse for Educational Facilities at the National Institute of Building Sciences provide information on planning for geologic hazards and building safety issues.

School preparedness is an emphasis of state law and local application in the four states that this paper features. In addition to general emergency plans, schools are required to prepare students, teachers and staff to protect themselves during earthquakes, tsunamis and volcanic events and to reduce risk beforehand, so that injuries and other losses will be minimized. This calls for practicing crisis plans with specialized emergency procedures, so that all will act instinctively during the seismic shaking. California law also mandates these actions for private schools. The “drop, cover and hold-on” exercise is practiced throughout the school year. Though little is formally done to monitor the use and effectiveness of these safety recommendations, most public school administrators and teachers have the information readily available though staff development trainings. The federal government instituted use of the National Incident Management System, a system for managing emergency situations based on the incident command system. Originally developed in California, this approach of responding to disasters by using uniform emergency management systems has proven effective. In California, local communities and school districts consistently use this state management system as a uniform response procedure.

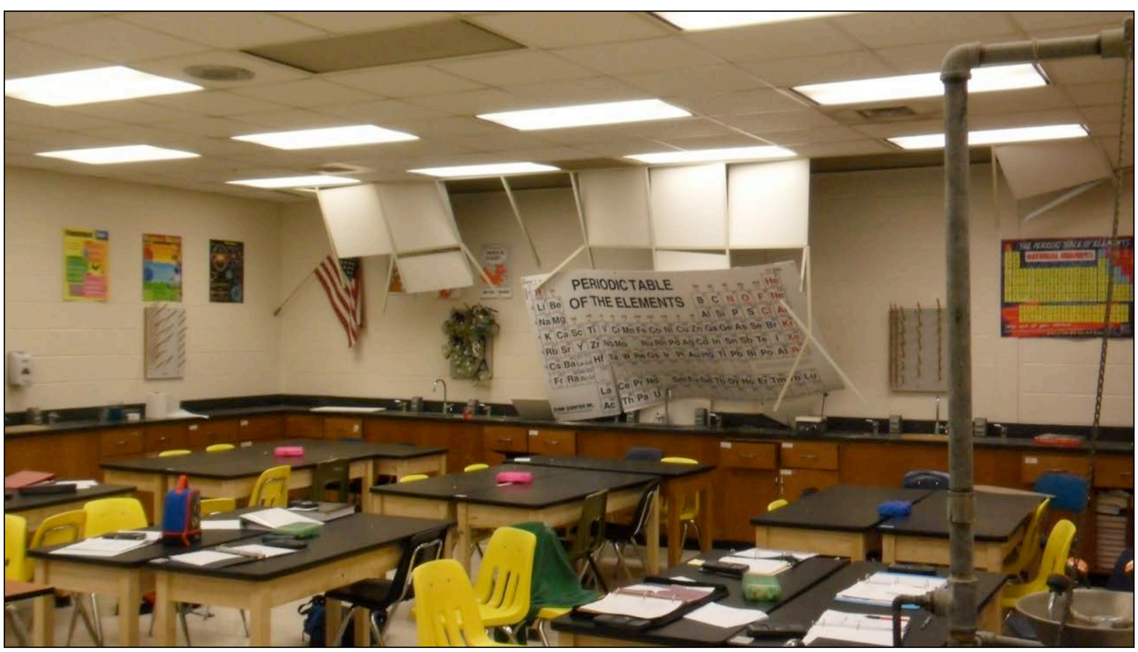

FIGURE 8: 2011 VIRGINIA EARTHQUAKE FALLEN CEILING SYSTEM AND DISPLAY - LOUISA COUNTY HIGH SCHOOL DAMAGE Image credit: EERI RECONNAISSANCE TEAM

The states of Oregon and Hawaii place special emphasis on tsunami safety, in addition to seismic shaking events. While the United States west coast is susceptible to tsunamis, more training and public awareness are in place in Oregon and Hawaii, due either to memory of specific natural hazard events or to the foresight of state officials at Oregon's Department of Geology and Mineral Industries (DOGAMI) and the Pacific Tsunami Museum in Hawaii. According to the Pacific Tsunami Museum, schools located in evacuation zones conduct annual tsunami evacuation drills. The schools sound an alarm for the exercise, and students and teachers evacuate to a safe location outside of the tsunami evacuation zone. Further, all states keep students safe at school after a disruptive event or natural disaster until an authorized, responsible adult fetches them. This keeps children off of the street and away from dangerous damage, tsunami surges and seismic aftershocks, under the protective auspices of trusted adults until family members arrive.

Curriculum Resources

Disaster readiness materials are part of the curriculum and are incorporated into educational programs at different grade levels. States are responsible for curriculum content. In California local school districts must adhere to state requirements but can use federally developed materials in classes, to the extent that they are helpful.

Educational resources for school districts on natural hazards are widely available from FEMA and the state emergency management agencies. They include publications such as the "Drop, Cover, and Hold" poster (FEMA 529); "Earthquake Preparedness for Childcare Providers" (FEMA 240); "Earthquake Safety Activities for Children and Teachers" (FEMA 527); "Seismic Sleuths: Earthquakes—A Teacher's Package for Grades 7-12" (FEMA 253); and, "Tremor Troops: Earthquakes—A Teacher's Packet for K-6, revised edition" (FEMA 159).

In Oregon, Hawaii and Washington, tsunami readiness is a statewide initiative. In 2007, the Pacific Tsunami Museum developed a tsunami curriculum for Hawaii schools called "The Tsunami Safe Curriculum." Washington's "Move to High Ground" publication was developed to teach students in primary and secondary schools about tsunami safety. Another state-developed book is used as a teaching tool about tsunamis for younger children in grades kindergarten to grade six: How the Smart Family Survived a Tsunami. Oregon's TsunamiReady™, TsunamiPrepared, is a multiyear program funded by the National Tsunami Hazard Mitigation Program to engage the state's at-risk communities in pre-emergency awareness and safety planning.

The Physical Safety of Schools

State governments and school districts address the disaster safety of students, teachers and school staff through a variety of region-specific measures. The most thorough measures are implemented in California, the most seismically at-risk state, where human and economic losses have been most substantial. Other states rely on the use of codes that are less restrictive and that primarily focus on new school construction with improved life safety standards.

California

California's new public schools must be earthquake resistant to meet the Field Act mandate that called for earthquake standards for new schools and for retrofit or replacement of schools constructed prior to 1933. The design of the Field Act was simple: it required an effective safety code applicable to schools; building design by structural engineers or qualified architects; conscientious plan review by licensed structural engineers; and rigorous full-time inspection by state approved inspectors. By comparison, other public assembly-type buildings only have spot-checking of construction and do not have a structural engineer observe construction or carry out a plan review.

By 1976, most public schools in California were designated as complying with the Field Act, though state authorities recognized that some schools initially deemed compliant were now considered susceptible to potential collapse. Additional laws passed in 1967 and 1968, the two Greene acts, called for evaluation and upgrades of pre-Field Act schools. Other pertinent legislation includes the 1972 School Building Sites Act requiring school districts to make site selection decisions that avoid construction close to geologic hazards; legislation designating Board of Education members as personally liable for failed preparedness efforts; and the 1986 Private Schools Act that extended the Field Act-concepts to new private schools (private schools opposed compliance with the more stringent public school standards and were powerful enough to avoid being subject to falling under the Field Act). In California, private schools are regulated by local government building departments, using the International Building Code, and are supposed to use structural engineers in the facility design.

In 1999, California's Assembly Bill 300 called for a new inventory of public schools, in order to identify which of the early Field Act-approved schools require additional mitigation. The State compiled a list of schools that warranted additional seismic evaluations based on a review of construction documents and districts reports. Ongoing scrutiny of the list continues, as state and local leaders assess the efficacy of efforts to implement seismic safety laws. Since 1998, California voters have approved nearly $US 45 billion of school construction funding, primarily to build new facilities or modernize existing buildings. Of these funds, $US 1.2 billion have been authorized for seismic safety or hardship projects.

Oregon

Oregon's statewide seismic risk management strategy to strengthen existing high-risk schools proceeds. The current approach that calls for basic building standards that will reduce damage and increase safety. Oregon assigned the expected safety performance standard in 2001 (Oregon Revised Statutes 445.400) as an unfunded mandate to communities. In 2005, the state legislature authorized $US 1.2 billion to fund necessary seismic upgrades; to date $US 22 million has been allocated. Oregon is developing an enhanced rapid visual screening (E-RVS) methodology to improve risk management.

Washington

Washington State has used the International Building Code as the standard for seismic safety, a practice applied in new facility construction. There is interest throughout the Puget Sound region in particular to apply disaster resistant school measures in school construction. Washington has accomplished considerable seismic retrofits using hazard mitigation grant funds and capital outlay funds, which are government monies allocated for risk reduction. Washington uses trust land revenue (funds derived from public land sales) for state school construction grants, with matching funds from local school districts. The state has generated $US 19 billion in school construction funds since 1993 to finance new school construction and major building upgrades, all built to seismic standards in effect at the time of construction.

Hawaii

Hawaii has adopted both tsunami and seismic safety building codes. In 2010, the State adopted the International Building Code 2006 Building Code (with amendments) as the Hawaii State Building Code, along with a suite of other codes, as part of the Hawaii State Building Code. This code applies safety standards to all new state buildings.

Utah

Salt Lake City, Utah has undertaken over $US 200 million in school safety projects since the 1990s, largely funded by taxes approved a super-majority of local voters. A supermajority is a majority (as two-thirds or three-fifths) greater than a simple majority. The Utah Seismic Safety Commission (USSC) and Structural Engineers Association of Utah (SEAU) recently evaluated a sample of 128 schools buildings out of more than 1,000 in the state. Of those screened, 77 school buildings (60%) were seismically suspect; 46 were deemed potential collapse hazards. The project demonstrated the need to conduct more assessments on all Utah schools to determine seismic vulnerability. Additional funds are needed for the tests and for establishing priorities for next steps.

The states examined here are the most forward acting in the United States on geologic hazards, in terms of addressing issues of school safety and disaster resilience in legislation. Little discussion or policy, however, directly articulates the concepts of *accountability*, *transparency* and *responsibility* with respect to physical safety deficiencies of schools. Though many agencies and commissions may play a policy or implementation role in these matters, no one state body is directly accountable for the whole of school safety.

Locally elected school boards direct school safety policies and programs; these bodies meet publicly and answer to voters. In California, laws exist that mandate the personal liability of school board members to enact safety and preparedness efforts, although there is no record of litigation regarding these measures. In effect, communities and their voting public become the final arbiters of risk identification, assessment and mitigation. As seen in many states, social concern about suspected school safety vulnerabilities frequently starts with the parents of students. Without specific legal clarity and defined accountability outcomes on school safety, it is likely that policies will continue to support today's inconsistent practices and to hinder substantial progress.

Engineering Performance and Minimum Code Requirements

States with adopted safety codes have varying engineering performance standards and code requirements. California, the most earthquake-experienced region, has more stringent performance standards for schools than do other states. All states have minimum code requirements that require collapse prevention for new construction.

In California, the Division of the State Architect (DSA) administers the Field Act to ensure schools and community college buildings are designed and constructed to its seismic standards, fire standards and accessibility standards for persons with disabilities. DSA currently has a $US 50 million budget and 300 employees, including 100 structural engineers, 50 architects and other building safety experts. It monitored the use by local school districts of $US 7 billion last year in 3,000 construction projects to ensure legal and safe building practices were used. The division reviews and approves construction plans; reviews continuous inspection programs, and certifies materials testing facilities, project inspectors and projects.

California's school safety objective is that "School buildings constructed pursuant to these regulations are expected to resist earthquake forces generated by major earthquakes of the intensity and severity of the strongest experienced in California without catastrophic collapse, but may experience some reparable architectural or structural damage." (Title 24, Part 1, Section 4-301, Safety of Construction of Public Schools, Administrative Regulations) DSA has authority to adopt and enforce strict building code regulations for public schools to ensure life safety and control building damage. In California private schools are regulated by local government building departments, using the International Building Code, and are supposed to use structural engineers in the facility design.

In states that use the International Building Code, the performance objective is "to safeguard the public health, safety, and general welfare through structural strength, means of egress, …and safety to life and property from fire and other hazards attributed to the built environment and to provide safety to fire fighters and emergency responders during emergency operations."

Description of State Program Results

Program outcome data on school safety initiatives are not widely available. California has the longest public record on seismic safety improvements of any state, but recent investigations show that information collection and verification efforts are uneven.

State bond measures and loans programs have been the economic engines of California's school construction program—with billions of dollars allocated to school construction and modernization in the last 13 years. California completed its first generation of seismic retrofits and replacements of collapse-risk schools in 1976 and is now in the early stages of a second generation of evaluations, retrofits and replacements of schools constructed in the early years of the Field Act. Data on the seismic improvements to schools statewide are available on the Division of the State Architect's website. California has not focused attention on tsunami- and volcano-resistant construction to any significant degree.

Other states have implemented more limited mitigation programs, and data on school retrofits and new construction are not consistently compiled. Oregon has allocated close to $30 million in safety upgrades with authorization for $1.2 billion for future work to improve schools previously assessed for structural deficiencies. Washington uses trust land revenue for state school construction grants with matching funds from local school districts. The state generated $19 billion in school construction funds since 1993 to finance new school construction and major building upgrades, all built to seismic standards in effect at the time of construction.

All told, these efforts aim at deliberate, incremental improvement of school building inventories in geologic risk prone states. In coming decades, it is likely that the most deficient existing school buildings will be seismically improved or replaced and that newly constructed schools will be built to more stringent, performance-based standards. Major alterations and additions to existing schools will also trigger seismic improvements. This anticipated progression rests on the fact that most states have adopted building codes that are systematically updated to reflect evolving, improved seismic standards. With consistent building code upgrades, substantial safety enhancements are integrated into construction and retrofit practice.

FIGURE 9: 2009-09-30 PADANG EERI RECONNAISSANCE TEAM ELEMENTARY SCHOOL NO.52
Image credit: EERI RECONNAISSANCE TEAM

Program Shortcomings

Political and fiscal obstacles hinder many of the well-intentioned safety programs established by the states. The Center for Investigative Reporting recently identified deficiencies in California's implementation and enforcement of state laws on safe building practices in school projects; administrative mishandling of construction and project records make analysis of program efficacy a serious challenge. Political interest groups have blocked seismically-at risk communities from tapping state funds dedicated to school safety improvements, and few mechanisms exist to monitor construction programs and building code enforcement.

Periodically the California Seismic Safety Commission has evaluated the effectiveness of California's Field Act Program. The latest report is entitled "The Field Act and Public School Construction; a 2007 Perspective," CSSC 2007-03, and includes three significant recommendations:

- Support for research using benefit-cost methodologies to analyze the full range of factors associated with Field Act statutes and administration, in order to recommend improvements or alternatives to existing practices;
- Support for administrative efforts that improve timeliness and technical accuracy of plan reviews, provide for consistent regulatory interpretation, and improve communications with implementing agencies; and
- Support for the Division of the State Architect's efforts to design and implement collaborative workload management processes that reduce planning and construction delays and, therefore, costs.

Of approximately 500 million square feet in California's school buildings, 14 percent were identified in 2002 as older, vulnerable types of construction that warrant seismic evaluations to determine if they can reliably achieve seismic safety. Though Oregon and Washington have made some progress in implementing safety upgrades for existing schools and use modern code standards for newly built facilities, progress is slow. To date, Oregon's efforts have resulted in 18 retrofit projects out of over 1000 existing schools statewide; tallies for Washington are not available. The financial resources needed for ongoing mitigation programs are often too much for governments to provide. Though laws exist calling for seismic improvements, fund allocations do not keep pace with the project needs. Given current economic conditions, it is difficult to see how states will continue their grants programs for school retrofit efforts at the current pace.

In addition, many seismically at-risk states have yet to establish programs to address building safety in schools. Midwestern states in the New Madrid fault area, and Utah's Wasatch Fault area are earthquake vulnerable and are launching technical investigations in order to learn more about the extent of seismic risk and how schools can be structurally evaluated. Both areas are working with federal agencies to better define safety issues but have not yet undertaken mitigation work. The recent Virginia earthquake reminded the eastern United States that it is not immune to damaging earthquakes. These developments may yield new programs, once initial research is complete and new information on regional risks is understood.

Conclusion: Need for a Comprehensive Approach

An integrated framework for school safety that includes pre-disaster safety planning, preparedness programs, risk reduction and resilience efforts is the optimal approach to provide safe facilities for students, teachers and school staff. Together, the elements provide a contingency system of safety that improves the school's readiness for a variety of potential disruptions. Having established such a system can help to curtail human injuries and deaths in a catastrophe, even when buildings are damaged.

Understanding hazards is the first principle in building a comprehensive safety program. Educating students, teachers, parents and school staff about the science of natural hazards and actions they can take before and during an event can provide the buffer of protection that can save lives and reduce injuries. Even if schools have not been renovated to withstand disruptive earthquakes, tsunamis, and volcanoes, understanding the nature of the disaster forces and potential consequences gives communities added measures of personal agency when the event strikes. Having a structured approach to protective actions (such as duck, cover and hold-on during a seismic event) or developing and practicing procedures for evacuations when tsunami or volcano warnings are issued is a core competency that school communities must support. School systems and nations that have enacted programs for facilities, students and staff safety typically have many of the following elements as staples of their institutional systems:

Preparedness measures such as emergency response plans, evacuation plans, recovery plans, preparedness training and drills for students, faculty and administrators are effective ways to alert people to the steps they can take for self-protection. The benefits accrued from consistent training include fewer human losses, as well as the capacity to effect improved response and recovery operations. Both international and national initiatives to promote active preparedness and response operations have demonstrated that at-risk regions/communities rebound more quickly when they have such programs already in place. Addressing non-structural hazards is essential as well. Not all casualties in a natural hazard event result from building damage. Falling hazards within the classroom, falling parapets and containers, and running cause casualties even when shaking is too weak to damage buildings in significant ways.

Curriculum requirements regarding the science of earthquakes, volcanoes and tsunamis and their effects are useful approaches to incorporate safety awareness and readiness efforts through academic/technical knowledge transfer. Understanding hazards is the first prerequisite to understanding how to improve safety.

Minimum zoning and building code requirements affect the location of school facilities in regard to earthquake hazards (faults, liquefaction or landslide potential areas), tsunami run-up zones and areas affected by volcanic hazards (blast, flows, gasses and ash). In areas susceptible to seismic shaking and other geologically induced hazards, it is crucial to employ prudent site selection reviews, so as to avoid building in risky areas. Location factors that add to a site's vulnerability to natural hazards include landslide or rock fall zones, or imperiling proximity to a coastal shoreline or volcano. Because schools cannot always be located on sites with minimal risk, these site selection review requirements are important, so that stakeholders understand the risk and make informed land use decisions.

Engineering performance standards in new and existing buildings for earthquakes, tsunami zones, volcanic hazards, fire and panic safety situations. For example, a building's capacity to resist many disaster impacts—shaking and ground failure, tsunami currents and debris—and to provide for post earthquake shelter is ideal. But this is a performance outcome that could be adapted to address local conditions and for school districts to consider and adopt individually. Such building structural resilience could be likened to using a broad-spectrum antibiotic rather than a narrowly targeted one when combating certain unidentified or drug-resistant microbes. The optimal performance would depend on the building's capacity to function in many ways as a safe haven. As well, the safety of existing vulnerable buildings is an issue distinct from proper construction of new ones; attending to these safety upgrades is a challenge to most regions at risk from damaging disasters. Past experience summarized in OECD's guidelines show that incremental approaches to facility improvements are feasible.

The OECD template provides the general guidance needed for an effective and comprehensive school safety program. In the states' programs reviewed here, most elements of the OECD framework are put to good use and have demonstrated efficacy over decades of implementation. APEC members should consider adopting the OECD guidelines for school safety as a best practice for use in regions geologically at risk, where school safety is imperative.

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Why Schools are Vulnerable to Earthquakes

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Abstract

School buildings collapse or are heavily damaged with alarming frequency in earthquakes. In the past decade, tens of thousands of children lost their lives when their schools collapsed. Many thousands more escaped serious injury or death solely because the earthquake that flattened their school occurred outside of school hours. In a world where we strive for education for all, why do schools collapse in earthquakes? This paper explores the physical reasons why—the characteristics of school buildings that cause them to be vulnerable to earthquake damage and collapse—using data from earthquake damage reports and seismic vulnerability assessments of school buildings. These data show that characteristics related to building configuration, type, materials and location; construction and inspection practices; and maintenance and post-construction modifications all contribute to building vulnerability. In particular, physical characteristics of school buildings such as large classroom windows, when combined with inadequate structural design and construction practices, create major vulnerabilities that result in earthquake damage. Using expert opinion in the published literature, we also explore the underlying drivers that allow unsafe school buildings to persist in vastly different settings around the world. These drivers include scarce resources, inadequate seismic building codes, unskilled building professionals, and a lack of awareness of earthquake risk and risk reduction measures.

Introduction

Schools have distinct physical and organizational characteristics that cause them to be vulnerable to earthquakes. Seismic vulnerability manifests itself most dramatically in building collapses that kill teachers and students, but also through hazardous falling objects such as parapets, via inadequate exits, and by a general lack of preparedness. In this paper, we explore vulnerability-generating characteristics and the underlying reasons that these characteristics manifest themselves in schools in different geographic, economic and cultural settings.

Of course, not all schools are alike. Differences in number of students, available land and local building practices, among other factors, manifest themselves in buildings that range from a single-room adobe structure in the Peruvian Andes to an eight-story concrete building in Mumbai. Despite these disparities in the global population of school buildings, a great many schools—especially in urban and peri-urban areas—tend to share similar characteristics and as a result, similar seismic vulnerabilities.

Data Sources and Methods

Data on school seismic vulnerability vary greatly in quality, quantity and availability throughout the world's earthquake-prone areas. In order to establish characteristics that create vulnerability, this study utilizes data from two main types of sources: reports of earthquake damage to schools, and vulnerability assessments of school buildings. Earthquake damage reports were obtained from the Earthquake Engineering Research Institute (EERI), Earthquake Engineering Field Investigation Team (EEFIT) of the Institution of Structural Engineers, other professional organizations, government agencies, individual authors, and private companies. TABLE 1 lists the data sources used in this study by earthquake. At the time of publication, school damage information was not yet available for some of the major earthquakes occurring in 2010 and 2011.

TABLE 1. SCHOOL EARTHQUAKE DAMAGE DATA SOURCES

Year	Location	Magnitude	School Damage Data References
2010	Baja California	7.2	EERI (2010)
2010	Haiti	7.0	UNICEF (2010), Green and Miles (2011), Holliday and Grant (2011), Marshall et al. (2011)
2009	Mongar, Bhutan	6.1	RGoB (2009)
2009	L'Aquila, Italy	6.3	EEFIT (2009), EERI (2009)
2009	Padang, Indonesia	7.6	EEFIT (2009), EERI (2009)
2008	Wenchuan, China	7.9	CEA (2008), Kabeyasawa et al. (2008), Miyamoto Intl. (2008), Xiong (2008)
2007	Pisco, Peru	8.0	EERI (2007), Taucer et al. (2008), Spence and So (2009)
2006	Yogyakarta, Indonesia	6.3	Spence and So (2009)
2005	Kashmir, Pakistan and India	7.6	ADB-WB (2005), Durrani et al. (2005), Langenbach (2005), NAS (2005), EEFIT (2006), Bothara (2007), Mumtaz et al. (2008), Greater Kashmir News (2011)
2003	Bam, Iran	6.6	Parsizadeh and Izadkhah (2005) Tierney et al. (2005)
2003	Bourmerdes, Algeria	6.8	Belazougui et al. (2003), Bendimerad (2004), Milutonovic and Massue (2004), Meslem (2007)
2003	Bingol, Turkey	6.4	Gulkan (2004)
2002	Molise, Italy	5.9	Augenti et al. (2004)
2002	Tblisi, Georgia	4.5	Gabrichidze et al (2004)
2001	Gujarat, India	7.7	Rai et al. (2001)
1999	Duzce, Turkey	7.2	Gur et al. (2009)
1999	Chi-Chi, Taiwan	7.7	Tsai et al. (2000), Yi (2005), Soong et al. (2000)
1999	Kocaeli, Turkey	7.6	Erdik (2001) Yuzugullu et al. (2004)
1998	Faial, Azores Islands, Portugal	6.2	Proença (2004)
1997	Cariaco, Venezuela	7.0	Lopez et al. (2004, 2007)
1996	Temouchent, Algeria	5.8	Bendimerad (2004)
1995	Kobe, Japan	6.9	Yomiuri Shimbun (1995), AIJ (1997), Nakano (2007)
1994	Beni Chougrane, Algeria	5.6	Bendimerad (2004)
1994	Northridge, USA	6.7	DSA (1994), LAUSD (1994)
1989	Loma Prieta, USA	6.9	EERI (1990)
1989	Chenoua, Algeria	5.7	Bendimerad (2004)
1988	Spitak, Armenia	6.8	EERI (1989), Yegian and Ghahraman (1992)
1988	Bihar, India and Nepal	6.6	Thapa (1989), Theruvengadam and Wason (1992)
1985	Michoacan, Mexico	8.0	Tena-Colunga (1996)
1980	El-Asnam, Algeria	7.3	Bendimerad (2004)
1971	San Fernando, USA	6.6	Jephcott and Hudson (1974)
1963	Skopje, former Yugoslavia	6.0	Milutinovic and Tasevski (2003) in Milutinovic and Massue (2004)

Note: Magnitudes are moment magnitude (M_w) obtained from the US Geological Survey; local sources may differ

Vulnerability assessments of school buildings come from a similarly varied set of sources, including government organizations, school jurisdictions and non-profit organizations. Vulnerability assessment data are much more readily available for urban and peri-urban schools, because cities are more likely to have conducted such assessments than have jurisdictions serving large, dispersed rural areas. Several vulnerability assessments conducted at the national or state/district level in New Zealand, Venezuela, the United States, and Nepal help to rectify this bias in the dataset. TABLE 2 shows the data sources used in this study. Additional organizations and jurisdictions have conducted vulnerability assessments (e.g., DSA, 2002), but the data were unavailable or not yet obtained at the time of publication.

TABLE 2. VULNERABILITY ASSESSMENT DATA SOURCES

Location	Assessment description	Reference
Africa		
Algiers Province, Algeria	526 buildings at 190 schools in 9 municipalities of Algiers Province surveyed for seismic vulnerability using simple survey forms	Meslem (2007)
Asia		
Central and North Asia		
Uzbekistan	Over 10000 schools assessed as part of State Program for School Upgradation	Khakimov et al. (2006)
Tashkent, Uzbekistan	Detailed vulnerability assessment of 3 schools; 2 retrofitted as part of SETI project; overview of general school building types and vulnerabilities in Tashkent	UNCRD (2007, 2009)
East Asia and Pacific		
New Zealand	Walk-through survey of 21,000 buildings at 2361 state schools conducted 1998-2001using Rapid Evaluation method developed by New Zealand Society for Earthquake Engineering; follow-up investigation in 2000.	Mitchell (2004)
Japan	125,000 public primary and middle school buildings nationwide assessed for seismic vulnerability by Ministry of Education, Science and Technology	Japan Times 2009 Nakano (2007)
Ota City, Japan	Assessment of 340 buildings at 91 elementary and middle schools in Ota City, Tokyo	Nakano (2007) Ohba et al. (2000)
Indonesia	Boen study of common vulnerabilities in Indonesian government school buildings, based on earthquake damage observation and analysis	Reported in ADPC Safer Cities 10
Indonesia	Vulnerability assessment of 4 schools; 2 retrofitted	UNCRD (2009)
Suva, Fiji	Vulnerability assessment of 6 schools; 3 retrofitted	UNCRD (2009)
South Asia		
Ahmedabad, Gujarat, India	Modified rapid visual screening of 42 schools	GHI (2005)
Baroda, Gujarat, India	Modified rapid visual screening of 58 schools	GHI (2005)
Surat, Gujarat, India	Modified rapid visual screening of 53 schools	GHI (2005)
Shimla, Himachal Pradesh, India	Vulnerability screening of 6 representative schools in Mashobra block of Shimla district (~20km from Shimla city); retrofit of 3 schools; Assessed schools are timber, RC and brick, dry stacked stone, stone and timber with mud mortar; stone with mud mortar	UNCRD (2009)

Delhi, India	Vulnerability assessment of 10 Government of Delhi schools by walk-through inspection by experienced structural engineers; comprehensive program including retrofit in one	GHI (2008)
Kathmandu Valley, Nepal	Inventory of Kathmandu Valley schools (643 schools, ~1100 buildings), vulnerability surveys of 378 schools (695 buildings)	GHI/NSET (1998); Dixit et al. (2000) Kandel et al. (2004)
Lamjung District, Nepal	Vulnerability screening of 745 school buildings; detailed assessments of some buildings, three buildings recommended for intervention	Archarya et al. (2011); GFDRR (2010)
Nawalparasi District, Nepal	Vulnerability screening of 636 school buildings; detailed assessments of some buildings, three buildings recommended for intervention	Archarya et al. (2011); GFDRR (2010)
Humla District, Nepal	Small sample of school buildings screened to provide sample of high-mountain schools for national vulnerability estimates	Archarya et al. (2011)
Seti Zone, Nepal	Qualitative overview of existing community built schools in Seti Zone, western Nepal.	Tamang and Dharam, 1995
Europe		
Italy	Survey paper of vulnerabilities in typical Italian school typologies; vulnerability assessment of 2700 important buildings including schools by Emilia-Romagna Regional Administration	Consentino et al. (2004)
Italy	General observations; assessment of 78 school buildings in Potenza province	Dolce (2004)
Istanbul, Turkey	Detailed assessment of 33 representative 3-5 story RC school buildings from ISMEP inventory	Kalem 2010
Latin America and Caribbean		
Quito, Ecuador	Initial screening of 340 "high-use" school buildings out of 700 schools, modified ATC RVS of 60 most vulnerable, detailed analyses for 20, retrofit designs for 15	GHI (1995)
Lima, Peru	28 schools in Barranco district and 80 schools in Chorrillos district of Lima evaluated using ATC-21 rapid visual screening and EMS-98 estimation of damage potential	Meneses-Loja and Aguilar (2004)
Venezuela	National vulnerability assessment of roughly 28,000 schools nationwide; Visual inspections of 250 schools using a vulnerability assessment checklist and detailed assessments and retrofits of 10 representative schools	Lopez et al. (2007, 2008)
North America		
Vancouver, Canada	302 buildings surveyed at all 108 Vancouver School Board schools	Transit Bridge Group (1990)
Charleston, South Carolina, USA	Detailed vulnerability assessments and retrofits of 6 schools in district 20 after prioritization exercise for all district schools	CCSD (2010)
Oregon, USA	Collapse risk assessment of 2185 K-12 public school buildings statewide using FEMA 154 rapid visual screening; 300 + buildings also have structural engineering reports	DOGAMI (2007)
Kodiak Island Borough, Alaska, USA	Detailed seismic and tsunami vulnerability assessments of all 14 Kodiak schools with 26 buildings; retrofit recommendations for 4 buildings	Eidinger (2006)
Utah, USA	Rapid visual screening using FEMA 154 of a sample of 128 public school buildings out of more than 1085 schools in state	Siegel (2011)
Memphis and Shelby County, Tennessee	Screening study of 349 buildings at 202 schools and other important buildings in Memphis and Shelby County, TN using ATC-21 plus locally developed method	Chang et al. (1995)

Where possible, we have obtained quantitative information on the relative prevalence and severity of various vulnerability-creating characteristics. However, in many cases, especially for earthquake damage reports, authors have provided only qualitative assessments of the most important vulnerability creating characteristics. Therefore, our method of determining relative prevalence of the various characteristics is based on whether a particular characteristic was cited as a cause of damage in damage reports or as a cause of vulnerability in vulnerability assessments. The level of detail contained in earthquake damage reports in the dataset varied significantly depending on the scope of the damage investigation (i.e., reconnaissance mission versus detailed survey), with many reports coming from relatively brief reconnaissance missions. Consequently, some causes of damage may have been omitted by the authors (especially of reconnaissance reports), due to incomplete coverage of the damaged area, lack of access, or simply because the authors viewed them as less important. In particular, objects that fell from the building exterior, as well as damage to finishes and contents inside the building, may have been omitted for these reasons. Also, this study of vulnerability-creating characteristics focuses on physical vulnerabilities rather than on preparedness deficits, though preparedness is certainly important and merits a similar investigation.

Quantitative information on the underlying drivers that are responsible for vulnerability-creating characteristics is much less readily available. In many, if not most locations, a set of complex and interrelated social, economic, political, cultural and technical factors combine to generate an environment that creates or perpetuates school seismic vulnerability. Due to the complexities involved and the lack of quantitative information, the paper relies on the judgment of local professionals as expressed in the literature, in order to identify the major underlying drivers affecting school earthquake safety in their location. Because the literature covers a limited number of countries, it is difficult to make definitive statements on the relative importance of the various drivers. However, we do attempt to make some basic observations.

Due to insufficient data, no attempt has been made to quantify whether school buildings are more vulnerable to earthquake damage or collapse than are other types of buildings. The author's judgment is that the relative vulnerability of schools versus other buildings depends greatly on the context: the types of buildings used for schools versus those most prevalent for other uses such as housing; the differences in how schools are designed and built versus other buildings; and the effectiveness of mitigation programs in reducing school vulnerability compared to their effectiveness in reducing the vulnerability of other building use types. In some cases, schools will be less vulnerable, and in other cases they will be more vulnerable than other buildings.

Characteristics that Create Vulnerability

The data sources used in this study mention many characteristics that either contributed to earthquake damage or are presumed to create the potential for earthquake damage based on the collective past experience of the earthquake engineering community. Earthquake engineering professionals have scientifically observed the damage caused by almost all of the major earthquakes in the latter half of the twentieth century, and researchers have simulated earthquake demands in thousands of laboratory experiments to better understand how earthquakes damage buildings. TABLE 3 shows the prevalence of each characteristic in the earthquake damage data set (TABLE 1) or vulnerability assessment data set (TABLE 2). Each characteristic, and why it makes buildings vulnerable, is explained in detail in subsequent sections.

TABLE 3. PREVALENCE OF VULNERABILITY-CREATING CHARACTERISTICS

Category	Vulnerability-creating Characteristic	No of. Earthquakes where Observed	No. of Vulnerability Assessments where Observed
Configuration	Large rooms - no cross walls	3	2
	Large rooms – no diaphragm	2	1
	Plan irregularity due to one-bay wide	3	4
	Plan irregularity general	0	11
	Captive columns due to partial height infill walls under windows	10	8
	Torsion due to windows on one side	1	3
	Torsion, general	0	6
	Weakness due to windows - masonry	2	5
	Soft or weak story	3	8
	Vertical irregularity, general	0	5
	Masonry gable walls	0	3
Building type	Vulnerable traditional construction	3	1
	Vulnerable modern non-engineered construction: non-ductile RC frame	2	0
	Vulnerable modern / older modern non-engineered construction: brick or block masonry	2	3
	Vulnerable modern / older modern non-engineered construction: improperly confined masonry	2	0
	Vulnerable modern / older modern engineered construction: non-ductile RC frame	11	8
	Vulnerable modern / older modern engineered construction: brick or block masonry	6	9
	Earthquake resistant traditional building types abandoned	1	0
	Standard types / plans have major seismic deficiencies	4	2
	Local materials generate weak or brittle buildings	3	3
	Heavy roofs	3	2
	Lack of seismic design understanding by engineers or architects	6	2
Location	Vulnerable sites / poor soil conditions	3	2
	Liquefaction	1	2
	Sloping site / landslides	0	1
	Cultural practices for site selection	0	1

Construction practices	Unskilled / low-skilled local labor	4	3
	Lack of awareness of earthquake-resistant construction practices amongst contractors	2	2
	Public contracting low bid rules	0	1
	Reducing quality to save money or time	3	0
	Poor construction quality, general	9	5
Construction inspection	Lack of inspection	4	0
	Corruption of inspection mechanisms	0	0
Materials	Poor quality engineered materials general	10	4
	Locally available materials weak	3	2
Maintenance	Deferred / not done, general	1	9
	No provision by builder or operator	0	1
Modifications	Subsequent structural modifications	2	2
	Ineffective retrofits	1	1
Falling hazards	Façade and exterior	4	10
	Interior / contents	6	6
Exit pathways	Only one door in classrooms	0	1
	Classroom door(s) open inward	0	1
	Windows barred	0	0
	Narrow halls and stairs	0	1
	Halls / stairs used for storage	0	1
	URM in stairwells	0	2
	Too few staircases	0	2
	Exit doors / gates locked	0	1
	Weak exit stair structures	1	0

Note: Total number of earthquakes with damage reports in data set is 32; total number of vulnerability assessments in data set is 31. Damage reports were aggregated for each earthquake.

Characteristics cited as causes of earthquake damage in damage reports for 25% or more of the earthquakes in the data set (eight or more citations) were captive columns due to partial height masonry infill walls under windows, non-ductile reinforced concrete frame construction, generally poor construction quality, and poor quality engineered materials. Characteristics cited in 25% or more of the vulnerability assessments (eight or more citations) were general plan irregularity, exterior falling hazards, unreinforced masonry construction, poor maintenance, non-ductile reinforced concrete frame construction, soft or weak stories and captive columns due to partial height masonry infill walls under windows. Characteristics cited in damage reports for 15% or more of the earthquakes in the dataset (five or more citations) were unreinforced masonry construction, lack of seismic design understanding by engineers or architects, and interior architectural and contents hazards. Characteristics cited in 15% or more of the vulnerability assessments (also five or more citations) were torsion, interior falling hazards, general vertical irregularities, generally poor construction quality, and weakness due to numerous windows reducing solid wall area in masonry buildings.

Though there is general agreement between the earthquake damage reports and the vulnerability assessments on most of the major causes of vulnerability, some notable differences exist. In particular, plan irregularities and torsion were commonly cited in vulnerability assessments but rarely mentioned in the earthquake damage reports. Possible reasons for this discrepancy include the previously discussed incomplete nature of most earthquake damage reports, and a tendency for damage observers to focus (understandably) on primary causes of collapse and major non-repairable damage. Systematic post-earthquake damage surveys that identify the causes of damage, rather than just the damage grade or damage level, would be extremely helpful in quantifying the relative importance of different vulnerabilities.

Configuration

Though a small number of schools use different instruction models, the majority of schools throughout the world are organized in the same way: each teacher leads a class of students (often numbering between 15 and 50) in a separate classroom. The number of classrooms in the school building(s) depends on the number of children the school serves. This way of organizing instruction, along with concerns for occupant comfort such as natural lighting and ventilation, causes school buildings to tend to have certain architectural configurations and characteristics that support the school's functioning. Several configuration characteristics can have significant implications for the building's seismic vulnerability; these are each described in detail in the following section.

Large rooms

In order to accommodate a cost-efficient number of students per teacher and provide unobstructed sight lines between students and teacher, classrooms tend to be larger rooms without interior supports. Classrooms also tend to be placed next to each other with a corridor or hallway and exterior windows on the other two sides, meaning that there are few if any cross walls outside the classroom to reduce the span of walls. When the building has a type of structural system that relies on the number and placement of walls for earthquake resistance (such as masonry bearing wall), fewer, longer walls without cross walls cause the building to be weak and lack redundancy. The floor and roof systems of classrooms must also span larger distances. In buildings where classrooms do not have a floor or roof system that behaves like a single member (what engineers call a *diaphragm*), the long spans allow the walls to move more and increase the chances that the roof/floor will pull apart and collapse.

For such buildings, schools are relatively more vulnerable than houses or apartments of the same construction type. Schools have inherently fewer walls for the same floor area due to the fact that classrooms are typically much larger than standard-sized rooms in residential buildings. In the 2008 Wenchuan, China earthquake, the Hanwang Primary School main building collapsed, while the adjacent dormitory of the same construction type did not. Both buildings had a type of precast concrete plank flooring system where the planks were not well connected and came apart if the walls moved much at all (Miyamoto International, 2008). In the school building, longer spans and fewer walls led to a disastrous collapse. FIGURE 5 shows similar collapses at Xingfu Primary School in the 2008 Wenchuan earthquake and at a school near Spitak in the 1988 Armenia earthquake.

FIGURE 5. PRECAST FLOOR PLANKS HANG FROM A WALL AT XINGFU PRIMARY SCHOOL IN DUJIANYAN CITY THAT COLLAPSED DURING THE 2008 WENCHUAN EARTHQUAKE AND KILLED MORE THAN 300 (LEFT). PHOTO CREDIT: CEA (2008). PRECAST FLOORS COLLAPSED IN THE INTERIOR OF A SCHOOL NEAR SPITAK IN THE 1988 ARMENIA EARTHQUAKE, KILLING MORE THAN 400 (RIGHT). PHOTO CREDIT: C.J. LANGER, US GEOLOGICAL SURVEY, COURTESY NATIONAL GEOPHYSICAL DATA CENTER.

Buildings one bay wide, often with irregular plans

Requirements and preferences for cross-ventilation and natural light, especially in settings where electrical power is not reliable or is expensive (or increasingly in industrialized countries, considered less environmentally friendly), lead to school buildings that are one or at most two classrooms wide. In settings with less land available, this results in buildings with irregular plans such as those resembling the letters L, H, T, and U, among others. Buildings with these shapes have what engineers call *re-entrant corners*, and buildings tend to suffer damage at these corners.

Large windows over partial height walls create captive columns or narrow piers

The large classroom windows that let in light and air often have stiff partial-height masonry walls below them. In concrete frame and masonry buildings, these partial height walls are much stiffer than the short sections of concrete column or masonry pier that run between the windows. During earthquake shaking, all the deformation and damage occurs in the short section of column, creating what is called the “captive column” or “short column” effect. In most cases this short section of the concrete column was not designed to take these forces and fails in a brittle manner, as FIGURE 6 and FIGURE 7 show. In masonry buildings, the narrow piers are not strong enough and crack and fail.

The presence of captive columns was the most commonly cited cause of school building earthquake damage in the damage reports reviewed for this study. Damage due to captive columns can readily be prevented with proper detailing. For example, schools in Peru with a new design providing elastomeric material between the partial height wall and the column performed very well in the 2007 Pisco earthquake (EERI, 2007).

FIGURE 6. CAPTIVE COLUMN FAILURES AT SCHOOLS DURING THE 1976 GUATEMALA EARTHQUAKE (LEFT) AND THE 1999 CHI-CHI TAIWAN EARTHQUAKE (RIGHT). PHOTO CREDITS: KARL STEINBRUGGE (LEFT) AND STEPHEN A. MAHIN (RIGHT), COURTESY NATIONAL INFORMATION SERVICE FOR EARTHQUAKE ENGINEERING, UNIVERSITY OF CALIFORNIA, BERKELEY.

FIGURE 7. CAPTIVE COLUMNS AT A SCHOOL DAMAGED BY THE 2008 WENCHUAN, CHINA EARTHQUAKE. PHOTO CREDIT: FENG YUAN (CEA, 2008)

Large windows on one side

For natural light and ventilation reasons, classrooms often have large windows on one side as mentioned above, with more substantial walls on the other side. In buildings that are one bay wide, this difference in stiffness can cause the building to twist during earthquake shaking even if engineers take precautions to avoid the captive column problem mentioned above. The windows can also make the building weak in the long direction because engineers cannot use braces or walls along the exterior. In the masonry building shown in FIGURE 8, the large windows on two sides made the narrow pier at the corner weak and especially vulnerable to damage.

FIGURE 8. LARGE WINDOWS ON THE EXTERIOR LED TO FAILURE OF THE NARROW BRICK PIERS AT THE BUILDING CORNER IN THE 1933 LONG BEACH, CALIFORNIA EARTHQUAKE. PHOTO CREDIT: HAROLD ENGLE, COURTESY NATIONAL INFORMATION SERVICE FOR EARTHQUAKE ENGINEERING, UNIVERSITY OF CALIFORNIA, BERKELEY.

Weak or soft stories

Multistory schools in some locations have one story—often the ground story—that has fewer walls (or masonry partitions) and therefore has less strength and stiffness than the adjacent story or stories. FIGURE 9 shows an elementary school with a collapsed ground story. This particular vulnerability is not specific to schools, and is often more prevalent in other types of buildings, such as residential buildings with commercial space or parking on the ground floor.

FIGURE 9. THREE-STORY ELEMENTARY SCHOOL WITH COLLAPSED GROUND STORY, 1999 CHI-CHI, TAIWAN EARTHQUAKE. PHOTO CREDIT: STEPHEN A. MAHIN, COURTESY NATIONAL INFORMATION SERVICE FOR EARTHQUAKE ENGINEERING, UNIVERSITY OF CALIFORNIA, BERKELEY.

Building Type

Buildings are usually classified by those who design them to resist earthquakes (i.e., structural engineers and architects) by the structural system that resists lateral and vertical forces and the construction materials used to build that system. Buildings that utilize a structural system or material that is inherently weaker and more brittle will be less earthquake resistant. Common vulnerabilities related to building type, listed below, are often prevalent throughout the local built environment, rather than being specific to the community's schools. However, the type of building used for a school has a major impact on the earthquake safety of the school—unsafe building types create unsafe schools.

Vulnerable forms of vernacular construction

Vernacular construction is a term used by architects and engineers to describe buildings that have been built without the input of design professionals. Vernacular buildings can be built with traditional forms of construction developed by local builders over time, built with modern engineered materials such as reinforced concrete without engineering design, or built with some combination of the two as in FIGURE 10. Seismically vulnerable forms of vernacular construction, both traditional and modern, are common practice in many areas of the world. Traditional vernacular construction tends to make use of readily available local materials, which may be inherently weak or brittle. Adobe (unfired clay) bricks, mud, and rubble stones are examples of local materials that tend to generate buildings that are weak and fail suddenly during earthquakes.

FIGURE 10. VERNACULAR SCHOOL BUILDING IN DHARAMSHALA, INDIA CONSTRUCTED OF MODERN MATERIALS – BRICK MASONRY AND REINFORCED CONCRETE – AS WELL AS STONE MASONRY. PHOTO CREDIT: JANISE RODGERS, GEOHAZARDS INTERNATIONAL

Earthquake-resistant traditional construction forms and practices abandoned

In a number of areas with a history of frequent damaging earthquakes, local builders have developed traditional forms of earthquake-resistant construction. These forms often combine materials that can resist bending and tension, such as wood or bamboo, with masonry materials, or use lightweight materials entirely. An example of traditional earthquake-resistant construction is a type of timber-laced masonry called *dhajji-dewari* that is used in the western Himalayas, especially Kashmir (for more information see Langenbach, 2005). However, earthquake-resistant forms of vernacular construction may have been abandoned for more vulnerable "modern" forms, either due to reduced availability of timber, loss of traditional skills, or a preference for more modern materials that are viewed as conferring higher status.

Standard building plans with seismic deficiencies

Many school jurisdictions use standard building designs for multiple schools, in order to reduce the costs involved in building design and to generate efficiencies in construction. In cases where a national or state level authority designs and builds schools, this practice results in many similar or identical school buildings throughout the country or region. If standard building plans have major seismic weaknesses, then many schools will be at risk of severe damage or collapse.

In the former Soviet Union, certain types of standard building designs, including school buildings, created by the central government collapsed in large numbers in the 1988 Armenia earthquake (Yegian and Ghahraman 1992; Khakimov and Tursonov 2006). Many of these buildings are still present in other areas of the Russian Federation and former Soviet Union republics, and present a significant earthquake risk. Similarly, standard precast school buildings used in a government building program to rapidly expand school capacity in Gujarat, India were heavily damaged in the 2001 Gujarat, India earthquake (Rai et al., 2001) as shown in FIGURE 11. A number of schools (and hospitals) in China's Sichuan province were built with the highly vulnerable structural system consisting of precast concrete floor planks resting on (and not properly connected to) unreinforced masonry walls or nonductile concrete frames with masonry infill walls, which were described in earlier sections (Miyamoto, 2008). Many schools built with this system collapsed, killing thousands of students. And finally, over 600 school buildings in Delhi, India and the surrounding region use a highly vulnerable roof/ceiling system consisting of stone slabs resting on steel beams shown in FIGURE 11 (see Holmes et al. 2009 for more information). This system is similarly vulnerable to the system used in China, and represents a tragedy waiting to happen should a strong earthquake strike Delhi during school hours.

FIGURE 11. DAMAGE TO PRECAST SCHOOL BUILDINGS CAUSED BY THE 2001 GUJARAT, INDIA EARTHQUAKE (LEFT) PHOTO CREDIT: A. MAHER PRASAD, INDIAN INSTITUTE OF TECHNOLOGY CHENNAI; COMMONLY USED HIGHLY VULNERABLE ROOF SYSTEM CONSISTING OF HEAVY STONE SLABS RESTING ON STEEL BEAMS IN DELHI, INDIA (RIGHT) PHOTO CREDIT: JANISE RODGERS, GEOHAZARDS INTERNATIONAL.

Heavy roofs

School buildings may have heavy roofs that generate large seismic forces. Heavy roofs may be preferred for thermal comfort; wind, rain or fire protection; aesthetic reasons (i.e., ceramic tiles); or due to a lack of availability of other materials.

Location

Schools may be located on sites vulnerable to landslides, flooding (from rivers, cyclone/storm surge, inundation due to dam failure, glacial lake outburst or tsunami), amplified earthquake ground motions or ground failure for a number of reasons. Schools are typically located in communities near housing, which restricts the choice of available sites. If the community cannot (or will not) make good land available, the school may be built on marginal land such as a hillside or in a flood plain.

Sites susceptible to ground failure

Schools may be built in areas that are susceptible to *liquefaction* (a phenomenon in which saturated sandy soils lose their strength due to earthquake shaking and flow like a liquid), landslides, or other types of ground failure. Buildings situated directly on top of a fault may be pulled apart when the fault ruptures during the earthquake. FIGURE 12 shows schools damaged by landslides and fault rupture.

FIGURE 12. GOVERNMENT HILL SCHOOL IN ANCHORAGE, ALASKA WAS PULLED APART BY A LANDSLIDE DURING THE 1964 ALASKA EARTHQUAKE (LEFT); COLLAPSED SCHOOL IN ADAPAZARI, TURKEY ATOP A FAULT RUPTURE DURING THE 1999 KOCAELI EARTHQUAKE – NOTE FAULT SCARP IN FOREGROUND (RIGHT). PHOTO CREDITS: KARL STEINBRUGGE (LEFT) AND ANDREW WHITTAKER (RIGHT), COURTESY NATIONAL INFORMATION SERVICE FOR EARTHQUAKE ENGINEERING, UNIVERSITY OF CALIFORNIA, BERKELEY.

Sites that amplify ground motions

Schools may be built on sites that can amplify earthquake shaking, such as those with soft soils or on ridge-tops or hilltops. For example in rural Nepal, school buildings are often constructed on hilltops, as are temples, for cultural reasons.

Construction Practices

Unskilled or low-skilled local labor

Local labor may be unskilled or low skilled, and such workers are often unaware of proper earthquake resistant practices. Community-built school buildings (i.e., those not built by professional contractors) are particularly prone to construction deficiencies cause by unskilled local workers. For example, schools in many parts of Nepal were built by communities during the government's implementation of the National Education System in the early 1970's due to a mandate that communities provide the school building. Most communities did not have skilled workers, and the resulting school buildings were of very poor quality (Tamang and Dharam, 1995). In Algeria, local construction firms in rural areas, which built many schools during the government's rapid expansion of the public education system, often had low-skilled workers that could not build reinforced concrete frame buildings as the designers intended, resulting in buildings with substantial earthquake vulnerabilities (Bendimerad, 2004).

Low-bid contracting

A cornerstone of public contracting in many locations—the selection of the lowest bidder—can create construction quality problems. If the construction contractors are not properly qualified during the contracting process, less-qualified or unqualified contractors will be building the schools, resulting in poor quality workmanship. In addition, the cost pressures involved with trying to win a low-bid competition can force the contractor to reduce the quality of materials and workmanship in order to make the job financially viable. Gulkan (2004) cites this practice as a cause of poor construction quality in Turkish schools.

Informal "value engineering"

Local contractors may commonly practice an informal type of "value engineering" in which they reduce material quantity or quality, or employ vulnerability-creating building practices (improper placement or curing of concrete, for example) to save money or speed up construction. Contractors consider this to be efficient rather than corrupt, and have often built many buildings that stand up perfectly well under everyday loads to prove their point. The fact that the building is still standing only because a major earthquake has not occurred is not even considered. For example, masons working in one of GHI's project areas in Dharamsala, India always used the same amount of reinforcing steel in concrete columns and beams (which was much less than the code required for earthquake resistance in that highly seismic area), because nothing had fallen down.

Construction Inspection

Inspection of construction is very important, in order to ensure that buildings are being built according to design. Lack of inspection removes incentives to follow plans and specifications and often leads to poor quality construction. In areas with high levels of corruption in the construction sector, the prevalence of corrupt practices such as the paying off of inspectors to approve poor quality or non-code-compliant work can lead to poor quality construction. Issues related to construction inspection are not confined to school buildings.

Materials

Poor quality engineered materials

Poor quality engineered materials such as cement, fired clay bricks, and reinforcing steel may be used for a variety of reasons. Though the data used in this study do not typically provide insight into the reasons why poor quality engineered materials were used in a particular area, some common reasons GHI and others have encountered include cost pressures, the fact that good quality materials may not be available locally, especially in rural areas, and an inadequate or complete lack of materials testing and inspection. For example, poor quality reinforcing steel is abundant and readily available in Karachi, Pakistan; good quality reinforcing steel is much more difficult to find.

In the case of concrete buildings, unskilled or low-skilled construction workers may produce poor quality concrete despite good quality cement, sand and aggregate, simply because they are not aware of how to properly mix and place concrete. In northern India, it is common to see concrete members with large "rock pockets" (locations where there is mostly rock aggregate and little cement) in buildings that are under construction being patched with cement plaster so that they look perfect. If only the workers placing the concrete were as skilled as the plasterers!

Weak locally available materials

Locally available materials may be weak or brittle, or may be difficult use to create earthquake resistant buildings. For example, local clay may be used to create adobe (unfired clay) bricks, mud mortar, or rammed earth walls. Fieldstones or river stones may be used to build rubble stone masonry buildings. Thin pieces of slate can be used for dry stacked stone masonry or heavy roofing tiles. All of these uses of local materials create buildings with high levels of earthquake vulnerability. FIGURE 13 shows a typical vernacular adobe school in Peru; buildings of this construction type are very weak and are often heavily damaged in Peru's frequent earthquakes.

FIGURE 13. A VERNACULAR ADOBE SCHOOL IN CHOCOS, PERU BEFORE SEISMIC RETROFIT – GEOHAZARDS INTERNATIONAL AND PARTNERS LATER RETROFITTED THIS SCHOOL. PHOTO CREDIT: BRIAN TUCKER, GEOHAZARDS INTERNATIONAL

Maintenance

Maintenance may be deferred, of poor quality, or not done at all. Poor maintenance weakens buildings, especially in harsh environments. Mortar in masonry buildings deteriorates and loses strength, weakening the walls that provide the building's (often limited) earthquake resistance. In reinforced concrete buildings, poor maintenance leads to cracking and corrosion of reinforcing steel, which causes the building to lose both ductility and strength. In wood buildings, poor maintenance can lead to dry rot, water damage and insect attack. Steel buildings can rust.

Though the sources used in this study do not typically give reasons for a lack of maintenance, several authors mentioned other fixed costs such as teacher salaries (Kenny, 2009) and a lack of provision for maintenance neither by those who built the school nor those who now operate the school (Tamang and Dharam, 1995).

Falling Hazards

Many school buildings have objects either on the façade or exterior, or inside, which can fall and injure or kill people. On the exterior, common falling hazards include unreinforced masonry parapets, poorly attached or deteriorated sunshades, poorly attached decorative veneers and tiles, masonry chimneys, flower pots, and rooftop or wall-mounted water tanks. Inside the building, large bookshelves and library stacks, pendant lights and fans, and chemicals in chemistry labs can all fall on students or block exit pathways.

Though no studies have been done specifically for schools, Petal (2003) found that 50% of injuries during the 1999 Kocaeli, Turkey earthquake were caused by falling objects alone, and a further 10% were caused by a combination of structural damage and falling objects (the remainder of injuries were caused by structural damage alone). In the United States, observations from the 1971 San Fernando (Jephcott and Hudson, 1974) and 1994 Northridge earthquakes (LAUSD, 1994; DSA 1994) indicated that California schools contained many falling hazards that would have injured and possibly killed students had school been in session at the time of the earthquake, and had students not practiced proper "drop cover and hold on" protective actions. FIGURE 14 shows fallen pendant light fixtures in California schools. Though the situation had improved by the time of the 2010 El Mayor-Cucupah earthquake due to enforcement of codes to prevent falling hazards, older school buildings in California's Imperial country still contained a number of falling hazards that could have injured students (EERI, 2010).

FIGURE 14. FALLEN LIGHT FIXTURES IN A CLASSROOM AND LIBRARY IN CALIFORNIA, USA. PHOTO CREDITS: NATIONAL GEOPHYSICAL DATA CENTER.

Inadequate Exits

In locations where building codes are not well enforced, school buildings may not have adequate pathways for students to exit the building safely and quickly. Inadequate exits (or means of egress) are very problematic if there is a fire, which can of course happen independently or as a result of earthquake damage. Also, it is standard practice to evacuate the school building after an earthquake, so exit pathways need to be clear.

Classrooms may have only one door, which opens inward to avoid blocking the corridor. Windows may have security bars that prevent them from being used as alternate escape routes. Hallways/corridors and stairwells are often too narrow, poorly lit or used for storage. Exit doors and gates may be locked for security purposes during school hours.

Underlying Drivers

Local professionals well versed in school design and construction in their location identified a number of underlying drivers that help to create an environment in which unsafe school buildings continue either to be built or to be used. TABLE 4 provides a snapshot of observations from a diverse group of economies. The diversity of these drivers leads to the conclusion that the reasons for school earthquake vulnerability are complex, inter-related and variable by context. However, some drivers seem to be present in many settings. The scarcity of resources for education affects prosperous and less-prosperous economies alike, as does the presence of inadequate building codes and the tendency to underestimate the seismic hazard. Drivers such as rapid school construction under Education for All initiatives, unskilled or unaware building professionals, and a lack of code enforcement occur predominately in developing economies regardless of geography. Except for drivers related to building code content and professional competence, the drivers enabling unsafe schools are outside the direct control of the engineers and scientists that make up the majority of the earthquake professional community. Social, economic and political factors create the remaining drivers and necessitate a broad and multifaceted approach to improving school seismic safety.

TABLE 4. OBSERVATIONS OF UNDERLYING DRIVERS

Underlying driver	Economy	Specific observations	Reference
Community built buildings	Nepal	Nepal's government stipulated that communities must build school buildings but did not provide any technical support. Due to a lack of skills, construction quality in most community built schools is very poor. Community responsibility ends with construction – communities view them as government's responsibility once completed – and so schools are not maintained.	Tamang and Dharam, (1995)
	Bhutan	Community built vernacular school buildings heavily damaged during 2009 earthquake	RGoB (2009)
Scarcity of resources	Global	Education departments typically have limited resources due to other pressing demands	Kenny (2009)
	Canada	Funding for infrastructure work was perceived to compete with basic educational needs of children so that basic human rights of children to education and safety were competing for same funds; responsibility for retrofits rests on the "already cash-strapped education sector"	Monk (2006)
	India	School administrators struggle to provide basic facilities, let alone seismically safe ones	Jain (2004)
Inadequate codes or seismic zoning	Italy	Inadequate codes before 1996; inadequate zoning	Dolce (2004)
	Algeria	Seismic hazard underestimated	Bendimerad (2004)
	China	Seismic hazard underestimated; codes inadequate prior to 1992	CEA (2008)
Lack of code enforcement	Algeria	Centralized government construction disbanded in 1990; no real enforcement thereafter	Bendimerad (2004)
	Turkey	No site inspections	Gulkan (2004)

Corruption of enforcement mechanisms	Global	Corruption circumvents regulatory mechanisms intended to provide safe buildings and renders them ineffective	Kenny (2009)
Unskilled or unaware building professionals	Algeria	Rural contractors less skilled; professionals can't design and build properly detailed RC frame buildings	Bendimerad (2004)
	India	No licensing or proficiency requirements for engineers; building professionals generally not competent in seismic safety related aspects	Jain (2004)
	Nepal	Most new school buildings in Nepal are built according to convention rather than designed	Bothara and Sharpe (2003)
	Pakistan	Unskilled builders constructed buildings poorly despite having good materials	Mumtaz et al. (2008)
	Turkey	No proficiency requirements for engineers and architects; no qualifications required for contractors	Gulkan (2004)
Lack of accountability	Turkey	Engineer of record is paid by developer, no independent inspection, no liability	Gulkan (2004)
Lack of risk awareness	Algeria	School directors and those responsible for school safety not aware of earthquake threat; parents unaware but very interested in seismic safety initiatives once informed	Meslem (2007)
	India	Many government officials unaware of earthquake threat, even in high seismic areas	Jain (2004)
	Pakistan	Professionals and builders unaware of earthquake threat in Kashmir region	Mumtaz et al (2008)
Failure to prioritize school safety	Canada	Schools not considered critical infrastructure, politicians not interested in fixing up "a bunch of tired old school buildings"; prisons, hydro dams, the legislature building, and even a provincial liquor store all retrofitted before schools	Monk (2006)
Urgent need for large numbers of new schools	Global	Education for all initiatives have created demand for large numbers of new schools in developing countries but earthquake safety is not typically mentioned	Wisner (2007) Kenny (2009)
	Algeria	Rapid expansion of education system after independence led in some cases to deficient construction	Bendimerad (2004)
	India	Gujarat precast schools, employed in order to rapidly construct large numbers of new government schools, badly damaged in the 2001 Gujarat earthquake	Rai (2001)

Conclusions and Recommendations

A review of school earthquake damage and vulnerability assessment data shows that a number of characteristics contribute to school buildings' earthquake vulnerability, including items related to configuration, building type, building materials, location, construction and inspection practices, maintenance, and subsequent modifications. Of these characteristics, non-ductile reinforced concrete frame construction, captive columns due to partial height masonry infill walls under windows, generally poor construction quality and use of poor quality construction materials were cited most often as causes of earthquake damage, while unreinforced masonry construction, poor maintenance, non-ductile reinforced concrete frame construction, soft or weak stories and captive columns due to partial height masonry infill walls under windows were cited as deficiencies most often in vulnerability assessments. Other commonly cited characteristics that create vulnerability were lack of seismic design understanding by engineers or architects, torsional irregularities, vertical structural system irregularities, and weakness due to numerous windows reducing solid wall area in masonry buildings. In addition to these characteristics that make the buildings themselves vulnerable to damage or collapse, schools often have exterior falling hazards such as masonry parapets, rooftop water tanks, and masonry chimneys. Inside school buildings, inadequate exit pathways and unrestrained items such as library shelving, storage cabinets, chemicals in chemistry labs, and pendant light fixtures create additional hazards.

The reasons for all of these varied characteristics that create vulnerability are typically complex and interrelated, but a number of local professionals have identified underlying drivers in the literature. The drivers include scarcity of resources, community built buildings, inadequate building codes or seismic zoning, lack of building code enforcement, corruption of enforcement mechanisms, unskilled building professionals, lack of accountability, lack of risk awareness, failure to prioritize school safety, and an urgent need for large numbers of new schools. Scarce resources, inadequate seismic building codes, unskilled building professionals, and a lack of awareness of earthquake risk and risk reduction measures were cited most often.

Due to schools' high occupancy and the terrible social consequences of school building collapses, gaining a better understanding of the characteristics and underlying drivers that generate seismically vulnerable school buildings is a crucial effort. Regrettably, efforts to collect and make available to earthquake professionals detailed data on earthquake damage to school buildings have fallen far short of what is needed. The author recommends that schools receive additional specific and focused attention in post-earthquake damage inventories conducted by earthquake engineers—beyond the often cursory chapter in an earthquake engineering reconnaissance report if that chapter is included at all—and that school jurisdictions share earthquake damage data they collect with the earthquake engineering community. Furthermore, the earthquake professional community should fully support research that provides quantitative information on the underlying drivers that create the conditions in which school building vulnerabilities are created or perpetuated.

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Corporate Social Responsibility in Disaster Risk Mitigation

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Introduction

Natural hazard events can deal devastating setbacks to the economic health of a community, region or nation, threatening lives and infrastructure. The corporate sector can play a significant role in building capacity and skills within the broader community to identify and reduce risks from natural hazards. Corporations have valuable human, material, technical and financial resources to contribute to such efforts. These investments are far more cost-effective than spending on relief and rebuilding, *after* a natural disaster exacts a heavy toll. The health of the corporate sector relies upon the well-being and prosperity of the broader community. For this reason, Corporate Social Responsibility (CSR) initiatives are more than good deeds: they are good business.

GeoHazards International has pioneered risk reduction CSR projects with industry leaders like Bechtel, collaborating to improve school earthquake safety, while offering corporate volunteers leadership opportunities and the chance to give back to their community in very direct ways. GHI regards CSR projects as opportunities to reach the larger community by involving government officials and inviting the media to milestone events. By working in schools to build awareness and reduce risk, CSR initiatives can raise general awareness and develop support for more challenging steps such as constructing new buildings correctly and retrofitting existing buildings found to be vulnerable. As CSR campaigns become established, corporate partners can encourage other companies to initiate their own school safety efforts.

Case Study: School Safety In India

Since 2007, in partnership with GeoHazards International (GHI), Bechtel Group Foundation has supported a school safety project in Delhi, India. GHI trains Bechtel Corporation employee volunteers to help schools prepare for earthquakes. Bechtel volunteers train school occupants on basic disaster safety, school preparedness planning, evacuation drills and more. In addition to the obvious benefits that this campaign provides to schools, the initiative helps the corporate organization by training employees, creating a safer workplace, and becoming more actively involved in the community. In India, this program provides a rare example of a corporate sector organization becoming directly involved in risk reduction, in the pre-disaster phase.

The role of the corporate sector in risk mitigation had not been considered significant, until the United Nations (UN) designated the 1990s the International Decade for Natural Disaster Reduction (IDNDR), with the basic objective of decreasing the loss of life, property destruction and social and economic disruption caused by natural hazards. The

IDNDR helped to promote a paradigm shift in the approach to natural hazard management from a focus on response and recovery toward a more proactive effort to create a culture of prevention, preparedness and mitigation.

In its mid-term review of the IDNDR at Yokohama, the UN unveiled a ‘Strategy and Plan of Acton to a Safer World’ that recommended, among other strategies, an ‘Integration of the private sector in disaster risk reduction efforts through promotion of business opportunities’. However, in a world reeling from a series of natural disasters—Hurricanes Andrew (1992) and Mitch (1998), the Orissa super-cyclone (1999), Iran earthquake (1990), Latur earthquake (1993), Northridge earthquake, Kobe earthquake (1995), Izmit earthquake (1999), Chi-Chi earthquake (1999) and more—the focus of the corporate sector remained on disaster response more than on risk reduction.

Still, the IDNDR has encouraged and begun the process of change. More and more governments are investing substantially in mitigation projects to reduce or eliminate the long-term risk to human life and property now. Studies have shown that a dollar spent on mitigation saves society four dollars in post disaster costs[3]; these numbers have motivated nations around the world to invest more in mitigation and risk reduction activities.

Corporate Social Responsibility strategies in risk management have been far slower to shift from a culture of response to one of mitigation. The primary areas of CSR investment continue to be health, education, environment and community development. The rather sporadic natural hazard-related investments of CSR programs typically occur in the aftermath of a local natural disaster and are confined to the provision of relief to affected communities. Preparedness and mitigation are not yet considered important by most businesses, and there are few examples of pre-event corporate-funded interventions.

Indian Scenario

The government of India recognized the importance of engaging the corporate sector in risk reduction, in a policy paper entitled ‘Disaster Risk Management and the Role of the Corporate Sector’. However, as in the rest of the world, few Indian organizations made significant contributions to risk mitigation. Corporations responded occasionally to events such as the 2001 Gujarat earthquake and the Indian Ocean tsunami.

Indian industry began to take notice of the importance of mitigation actions when the Gujarat earthquake impacted industries, and a number of these closed down or suffered extended business disruptions. Most of the affected industries had employees (and their families) who were totally unprepared for the disasters that struck their communities and disrupted their lives. When communication and transport infrastructure were damaged, and the communities that they served were adversely affected, this ripple effect persuaded a few industries to launch long-term mitigation activities on their premises and to extend these efforts to the community around them. However, such initiatives are few and far between and remain focused on the area affected by the Gujarat earthquake.

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[3] See, for example, “Mitigation Saves: An Independent Study to Assess the Future Savings from Mitigation Activities” conducted by the Multihazard Mitigation Council in 2005 with funding from the Federal Emergency Management Agency (United States).

The Bechtel GHI School Safety Initiative

Understanding that earthquake safety was an ideal sector in which to invest their Corporate Social Responsibility funds, and that working in local schools would be a very effective way for employees to give back to the community, Bechtel began working with GHI to reduce the earthquake risk in one school. However, both organizations recognized the "bench strength" of Bechtel's office in Gurgaon and agreed that GHI's role in the project would be to build capacities within Bechtel by training employee volunteers to carry out various steps towards school safety.

In December 2007, the Bechtel Group Foundation funded GHI to form an innovative partnership with Bechtel employees to protect school children in Gurgaon, India from the threat of earthquakes. Like other parts of the Delhi metropolitan area, Gurgaon faces a high earthquake risk. The need to make Gurgaon's schools earthquake-resistant had become more apparent in light of school collapses in the 2001 Gujarat, 2005 Kashmir and 2008 Sichuan (China) earthquakes, which resulted in the deaths of tens of thousands of children. Recognizing the need to prevent a similar disaster in Gurgaon, a group of Bechtel employees volunteered their time to learn from GHI about how to become school earthquake safety advocates in the local community.

Selection of Employee Volunteers

FIG. 1. BECHTEL EMPLOYEES PRACTICE A "HAZARD HUNT."

Even though GHI's role in most of the projects that it undertakes is to build capacities of partners, this partnership was a unique model that had not been implemented before by Bechtel or by GHI. The Bechtel management appointed a project lead, who contacted colleagues by email to explain the project and to ask for volunteers. Twenty-five volunteers were selected for training from roughly forty-five applicants, based on the time that they would be able to dedicate to this project outside their working hours. The team included men and women of different ages, backgrounds, trades, duties and responsibilities. The project was an opportunity for Bechtel to bring together employees from different departments to work together on a unique project.

Training of Volunteers

GHI organized a three-day intensive training for the first group of employee volunteers on the Bechtel premises over two weekends. The first session introduced the project and the importance of working in the community, covered earthquake basics and local earthquake hazard in Gurgaon, fire safety and introduced disaster risk reduction measures. The subsequent training sessions described how to work in the project school and provided detailed information on how to lead school disaster safety activities.

FIG. 2. BECHTEL VOLUNTEERS REVIEW THE USE OF POWER TOOLS TO ANCHOR FALLING HAZARDS.

The sessions included detailed discussions of how to identify and mitigate falling hazards. The trainees were coached to identify hazards within a school campus through "Virtual Hazard Hunts" using photographs and videos from schools and also through practical hazard identification exercises on the Bechtel premises. Through the hazard hunt, volunteers not only learned to identify falling hazards and to use a hazard hunt checklist, but also identified several falling hazards in the offices that would make their offices safer, when fixed. The volunteers also learned how to mitigate falling hazards; they enjoyed learning to handle tools and to get their hands dirty!

Because the volunteers would train teachers and students of all ages, special sessions were offered on how to communicate effectively with various age groups. Other sessions covered how to develop evacuation plans for various hazards, how to use an evacuation planning checklist developed by GHI, how to conduct a disaster preparedness drill, how to document lessons learned in drills and revise the plan. Family preparedness was another important component of the training, because teachers would need to have their own families prepared, in order to be able to carry out their responsibilities at school without undue anxiety, following an earthquake.

At the end of the training, the volunteers divided into two or three person teams responsible for various project activities to be taken up at the school. There were teams for liaising with the school administration, training teachers and training children. GHI evaluated the effectiveness of its training sessions by administering short quizzes at the beginning and end of these sessions and noted that the volunteers performed well, demonstrating both the impact of the training and their enthusiasm and receptivity.

One of the important aspects addressed in training was the post-disaster Child Release Policy. An earthquake-damaged city is a completely different environment from the one through which a child normally travels to and from school. Broken buildings, surface ruptures, live electric wires, glass and human predators are some of the hazards that can harm a child trying to find her way home in a damaged city. It is important that schools retain children at school in a crisis and hand them over only to pre-authorized persons, as per a policy framed by the school. Most schools do not have such a policy. Preparedness drills normally end when children return to class after an evacuation drill. However, in a real event, the school's responsibility ends only when the last child is handed back to his or her parents or an authorized person. A child release policy provides additional safety for children.

Identifying the Host Schools

Soon after training the volunteers, the GHI-Bechtel team initiated the process of selecting a host school. The criteria for school selection were size and administrative philosophy. It was decided at the outset that a mid-sized school would be chosen. GHI-Bechtel was keen to identify a school with proactive management, willing to take up new ideas and activities that would serve as an example for other schools to follow. After visiting many schools, the team selected the Gyan Devi group of schools with about 1100 students headed by a retired Army officer who had been looking for technical support for disaster risk management activities in their school. Gyan Devi Public School is the flagship school of the Colonel's Education Society group of institutions. The Society runs three other schools in the Gurgaon area.

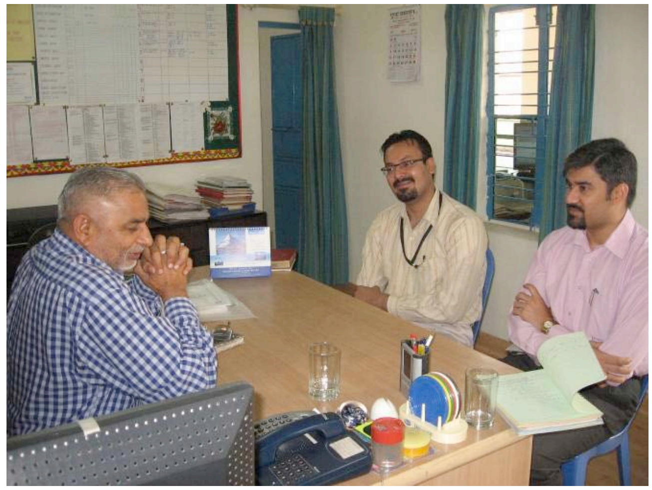

FIG. 3. BECHTEL VOLUNTEERS MEET WITH THE HEADMASTER.

School administrators provide leadership and set the tone for school safety, and their proactive choices can determine whether or not children are prepared and safe from hazards. The Gyan Devi administration demonstrated its commitment to earthquake safety and its enthusiastic and wholehearted support toward undertaking earthquake risk reduction activities.

Introducing Disaster Risk Reduction to School Administrations

FIG. 4. TEACHERS LEARN EARTHQUAKE BASICS.

The volunteers led the initial meeting with the school administration, introducing Bechtel and GHI and outlining the proposed activities to be carried out at the school. They answered questions posed by the administrators regarding each activity, the personnel who would be involved from the school and time required. They guided the school throughout the course of the training and initiated formation of a School Safety Committee. The Committee consisted of the focal teacher for the project from the school, the Principal, Vice Principal, six teachers, two parent representatives and four student representatives. The team insisted on gender parity within the committee.

The school management was somewhat hesitant to include parent representatives on the committee and finessed the problem by including two teachers whose children were also students. The school management also appeared reluctant to include personnel from outside their immediate circle of influence in a project, which would bring about changes in their outlook regarding safety within the school. The project team noted this and other lessons learned, so that they could adapt their approach in future training discussions.

Training Teachers and Students

FIG. 5. STUDENTS OBSERVE SHAKE TABLE DEMONSTRATION.

Volunteers worked with school administrators to set dates for the awareness-raising programs for teachers, students and parents. The school administrators were enthusiastic about the teachers' training and arranged for teachers from all four Gyan Devi schools to attend the training program. This program demonstrated both the effectiveness of the volunteer training and the creativity of volunteers. The volunteers handled the sessions professionally, confidently answering all of the questions that teachers raised.

FIG. 6. YOUNGER CHILDREN LEARN THROUGH STORIES.

The calendar for training children was decided after consultation with the committee, and the Bechtel volunteers taught age-appropriate lessons to groups of students. The kindergarten students were the first group to be addressed; the challenge lay in explaining earthquake safety to such young children without making them anxious. To assist in this effort, GHI called on a pre-school communications expert from "Sesame Street India" to train the Bechtel volunteers in basic principles of communicating with small children, bearing in mind their short attention spans. She emphasized using positive stories to teach and urged volunteers to tap into the power of children's imaginations and helped the volunteers develop stories that would enable children to understand appropriate behavior in an earthquake. The stories were used to explain earthquakes and what students should do. A tabletop shake-table model was used to demonstrate earthquake shaking and how to prevent objects from falling. The storytelling session was so interesting that the children, their teachers and the volunteers themselves became engrossed in the stories. All of the children were given coloring books and other materials on earthquake safety to take home and share with their parents.

The volunteers worked tirelessly to complete the training for all classes, which spread over a few days. For older students, the volunteers incorporated videos taken during actual earthquakes into their presentations and used the shake-table to demonstrate falling hazards. The students were eager to learn about earthquakes, because their teachers who had attended the earlier awareness-raising session had already introduced them to the basics of earthquakes and had initiated several earthquake-related school projects.

Identifying and Mitigating Hazards

FIG. 7. A BECHTEL VOLUNTEER FIXES A BOOKCASE TO A WALL.

Classroom sessions were followed by a "hazard hunt" in the classrooms, library and science laboratory. The volunteers led the students in looking at their surroundings with 'earthquake eyes' and encouraged them to start thinking about means of anchoring or bracing falling hazards. The volunteers and the Committee went around the entire school campus checking for falling hazards, electrical and fire hazards and hazards due to improper exit conditions.

FIG. 8. A GHI EMPLOYEE FIXES A CABINET TO THE WALL.

In most of the classrooms, the doors opened inside and would create a bottleneck in an emergency evacuation. The volunteers discussed the possibility of changing the doors to swing outside with the school management. Because this would be an exercise that would incur financial investment and would disrupt school functioning, the administration decided against it. The volunteers and the committee decided to introduce the concept of a 'door monitor' in each classroom. The desks closest to the doors in every classroom were marked with the words 'Door Monitor,' and teachers and children were made aware that the occupant of these marked desks at any point of time would assume the role of a door monitor and would open the door in the case of an emergency evacuation.

The volunteers recorded the students' findings on hazard hunt forms and compiled the information into a list of items to be anchored or braced. A few Bechtel volunteers, who specialized in anchors, fasteners, and anchoring solutions helped the other volunteers select the optimal methods of anchoring falling hazards at the school. The volunteers returned to the school on subsequent weekends to fix the falling hazards in the library, science lab, staff room and classrooms. They also trained and involved selected members of the non-teaching staff of the school in these activities so that they help the school carry forward the activities in future.

Conducting Evacuation Planning and Preparedness Drills

The volunteer team in charge of evacuation planning consulted extensively with the Committee to develop an evacuation plan for each room in the campus. They identified corridors and staircases where a mass evacuation could cause congestion and identified alternate routes for classrooms, libraries and labs. A detailed plan was drawn up, and the volunteers helped the Committee in presenting the plan to the teachers. It was decided that non teaching staff will be deputed to control 'traffic' in certain areas of the school where a bottleneck was likely to occur, and that another sensitization session for the non-teaching staff of the school would be conducted to familiarize them with the evacuation plan and their roles during and after the evacuation. There were children with special needs in two classes: 'buddies' were assigned and trained to help these children to the designated assembly areas.

FIG. 9. TEACHERS TAKE ROLL TO IDENTIFY STUDENTS.

The volunteers wanted to ensure that the drills would go smoothly and discussed the dates for the first drill with the school management to ensure that staff and students would be able to devote time to this important exercise. Once dates were finalized, volunteers joined the Committee in displaying evacuation plans prominently in all rooms of the school. The groups confirmed that hazards noted earlier had been removed or corrected.

On the morning of the drill, the Committee and volunteers addressed the school assembly to reiterate the importance of following one's assigned role in the evacuation drill. On orders from the Principal, a special bell initiated the evacuation procedure. Once teachers and students had exited to the assembly area, teachers took roll and identified 'missing' students. After an address by the Principal, students returned to their classes. Following this, the Committee and volunteers held a meeting with the teachers to discuss the lessons learned. The Committee and the volunteers noted all suggestions, in order to make improvements in the plan.

The Committee also helped the school to design a child release policy to enable the release of students to parents or their pre-authorized pick up person. As per this policy, parents were requested to fill up a disaster release card listing all adults who may need to come to pick-up the child, with photographs or their identity card numbers. Children will be released only to authorized personnel who show their listed identity cards.

FIG. 10. STUDENTS PRACTICE SAFE EVACUATION.

End of Project Review

Bechtel conducted an end of project review of activities, conducting interviews with the volunteers, the school administration, teachers and students. It became evident that this partnership was a win-win-win partnership. GHI gained as the project was an excellent entry point to work with schools in Gurgaon, where GHI had not worked before. The partnership with Bechtel helped GHI develop various training materials on school safety, which have been used across India in other training programs. Gyan Devi School gained as the school, its teachers and students became safer and were able to take positive steps towards a comprehensive safe school. Parents of the students are happy that the school is taking such proactive measures to ensure the safety of their wards. Bechtel gained as the employees enjoyed the leadership opportunities and the chance of giving back to the community. This was also the first time that many employees from different departments and projects within the Bechtel offices came to work together. Working together helped develop camaraderie and break down communication barriers. The trained employees also conducted training sessions within the Bechtel offices and raised awareness about maintaining a safe workplace. While earlier CSR interventions had been more about writing a check for a good cause, the Bechtel employees themselves carried this project forward, with GHI facilitating activities and providing appropriate technical support.

Sustainability

Bechtel and GHI had no doubts that this project should continue and soon identified a fresh set of volunteers to train. The partners carried out similar activities in many other schools in and around Gurgaon. The partnership is now its fourth year and has worked in a retirement home in Gurgaon. GHI has built upon the knowledge gained from serving these schools to launch earthquake risk reduction activities in schools for children with special needs, such as the Delhi Blind Relief Association and at the Action for Autism for children with autism.

School Interventions under the Bechtel-GHI project	Year	Awareness generated		
		Teachers	Students	Non teaching staff
Saraswati Bal Mandir School	2011	287	18	6
Balvantrai Mehta Vidya Mandir School	2011	35	1,200	15
DAV Public School, Gurgaon	2010	173	2,965	55
Chiranjiv Bharati School, Gurgaon	2009	35	650	27
American Montessori School, Gurgaon	2009	36	375	32
Gyan Devi Montessori School, Gurgaon	2009	11	283	16
Gyan Devi Public School, Gurgaon	2008	63	1,100	29

TABLE I. SUMMARY OF TRAINING RESULTS.

Conclusion

The Bechtel-GHI initiative has been cited by agencies such as the National Disaster Management Authority (NDMA) of India as a unique model of corporate social responsibility. More and more corporate agencies have realized that CSR is no longer just about making a cash donation: it is in the interest of the corporate organization to be involved in the activities. Engaging in such activities helps the organization attract, motivate and retain good staff members. Corporate offices will increasingly realize that the decision to engage in risk mitigation is not just a moral decision—it is a business decision. Corporations are no longer asked ‘if’ they engage in disaster risk mitigation, but ‘how’ they are engaged. Soon, the question will be ‘How *well* are you engaged in mitigation?’

Seismotectonic Setting and Earthquake Hazards in the APEC Region

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The overarching goal of the Workshop on School Earthquake and Tsunami Safety in APEC Economies is to help the member APEC economies to evaluate their policies relative to earthquake safety in schools. Understanding the earthquake risk, its potential impact on the safety of children, and potential economic impacts all are elements of this consideration. In this paper, we describe the earthquake hazard in the APEC region, so that school officials in the economies can better understand the extent of the hazard, how it varies within each economy, and how hazard levels compare with other economies. This paper focuses attention on a fundamental aspect of school safety in earthquakes: understanding the global geological context of earthquake occurrence. It is impossible to address the issues of school safety without first understanding the basic geological processes that lead to earthquake occurrence, how patterns of earthquake distribution relate to geography and human population and development patterns, and then to examine earthquakes' potential impacts on societal infrastructure.

This paper first examines some general issues related to earthquake risk; we then provide an overview of the emerging field of seismotectonics, which examines the global-scale Earth processes that manifest themselves in dynamic, and frequently destructive, aspects of life on planet Earth: earthquakes, volcanic activity, tsunamis, and the deformation processes that produce the landscapes in which we live. Finally we provide some examples of specific earthquake impact scenarios that provide insight into the potential impact of future earthquakes on individual APEC economies. We conclude with some recommendations on earthquake hazard mitigation and school safety.

FIGURE 1. THE DEVASTATING IMPACT OF THE MARCH 2011 TOHOKU EARTHQUAKE AND TSUNAMI. AERIAL PHOTOGRAPH FROM THE TOWN OF WAKUYA (US NAVY PHOTOGRAPH, NO. 110315-N-IC111-592.)

Context: Natural Disasters and Sustainability

Sustainability is often defined as "meeting the needs of the present without compromising the ability of future generations to meet their needs." Sustainability focuses on the interrelated issues of environmental stewardship, resource use and conservation, and social and economic equity. The perceived challenges to societal sustainability are commonly focused on issues of human-induced environmental change and use of energy or other natural resources. However, it is not only human activities that can challenge the survival of civilizations. The stark experience of the past several years—as manifested by devastating natural disasters in Indonesia, China, Haiti, and Japan—has demonstrated that among the greatest challenges to sustainability are the large-scale natural disasters that crumble infrastructure, destroy local economies, trigger migration of environmental refugees, generate massive losses of embedded energy resources, and exacerbate pre-existing economic, environmental, and social challenges. A natural disaster can be further compounded by the secondary failure of complex human engineering systems and resulting environmental consequences—as demonstrated by the failure of Japan's Fukushima power plant. The ability to prepare for, and recover from, such environmental disasters is the ultimate test of a sustainable society. Sustaining society in the face of the sudden and severe challenges of natural disasters in turn requires advance planning for disaster mitigation, investment in research and education, and collaboration and cooperation on a global scale—exactly the targets of the Workshop on School Earthquake and Tsunami Safety in APEC Economies.

Among the public institutions facing threats of natural disasters, schools are, sadly, often the most underprepared. Safe schools are critical to providing students with 21st century competencies and skills, so that they may contribute to vibrant societies. Schools also serve as emergency shelters and can be used to house, feed, and care for the local population and in doing so, help to minimize post-event disruptions. School safety programs are "gateway projects:" they open the gate to the entire community and provide a forum to discuss disaster preparedness efforts. Schools also serve as ideal institutions to communicate scientific knowledge to communities in the developing world. Unfortunately, schools all too frequently bear the greatest impact of natural disasters. A combination of poor land-use planning, weak design standards, inadequate construction materials, the peculiar design characteristics of school buildings, and inadequate enforcement of existing building codes has led to widespread failure of school buildings—and consequent impact on children—in major earthquakes and tsunamis worldwide. The goal of this workshop is to apply advanced scientific and engineering knowledge to mitigate the disproportionate impacts of geological disasters on schools.

The past decade has seen an extraordinary spate of natural disasters, with huge economic and social impacts. The six major earthquakes listed in Table 1 have resulted in some three-quarters of a million lives lost and cost over half a trillion dollars in economic damage. Like many of the most devastating disasters of the past century, all of these recent natural disasters were triggered by earthquakes. The damage inflicted by these six earthquakes is already far greater than that of the previous quarter century's earthquake-related disasters combined. And the long-term impact of these disasters is yet to be fully determined, as the affected countries are still in the process of rebuilding; their social and psychological cost is incalculable. The impacts of these recent earthquakes suggest the impact of these recent disasters was exacerbated by human infrastructure and decades of public and private decisions that have influenced patterns of development.

Year	Magnitude	Natural Disaster	Casualties (Estimate)
2001	7.7	Bhuj (Gujarat) Earthquake (India)	30,000
2004	9.2	Indian Ocean Earthquake and Tsunami (Indonesia)	298,000
2005	7.6	Earthquake in Kashmir (Pakistan/India)	87,000
2008	8.0	Earthquake in Sichuan (China)	68,000
2010	7.1	Earthquake in Port-au-Prince (Haiti)	230,000
2011	9.0	Tohoku Earthquake and Tsunami (Japan)	20,000

TABLE ONE. MAJOR EARTHQUAKES, 2001-2011.

Earthquakes, Faulting, and Plate Tectonics

In order to better understand the potential risk of future earthquakes in the Asia-Pacific region, we need to briefly review some of the global-scale processes that produce earthquakes and their related secondary effects. Since early in the history of seismology, it has been widely recognized that the global distribution of earthquakes (Figure 2) is highly non-uniform.

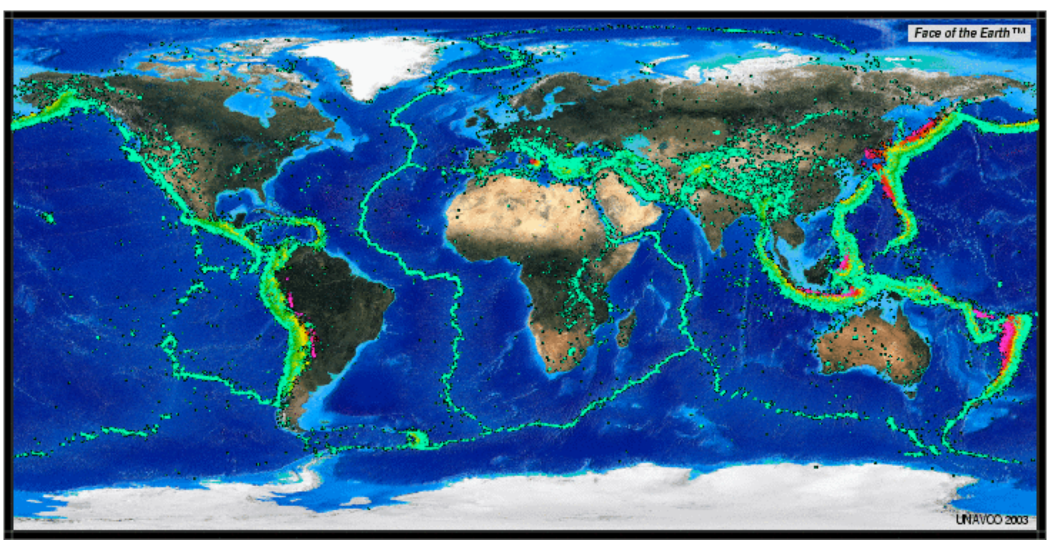

FIGURE 2. SEISMICITY OF THE EARTH, ON A BASEMAP OF GLOBAL TOPOGRAPHY. FROM UNAVCO'S JULES VERNE VOYAGER (HTTP://JULES.UNAVCO.ORG).

Belts of activity trace a narrow zone snaking through the world's ocean basins, define an intense 'ring of fire' surrounding the Pacific Ocean, mark a broad swath along the southern margins of Europe and Asia, and trace a belt through the eastern half of Africa. With the advent of the theory of plate tectonics in the 1960s, we now recognize that this behavior is controlled largely by the behavior of Earth's tectonic plates. The plate tectonic theory holds that the surface of our planet is fragmented into a mosaic of some 16 'tectonic plates', shown in Figure 3.

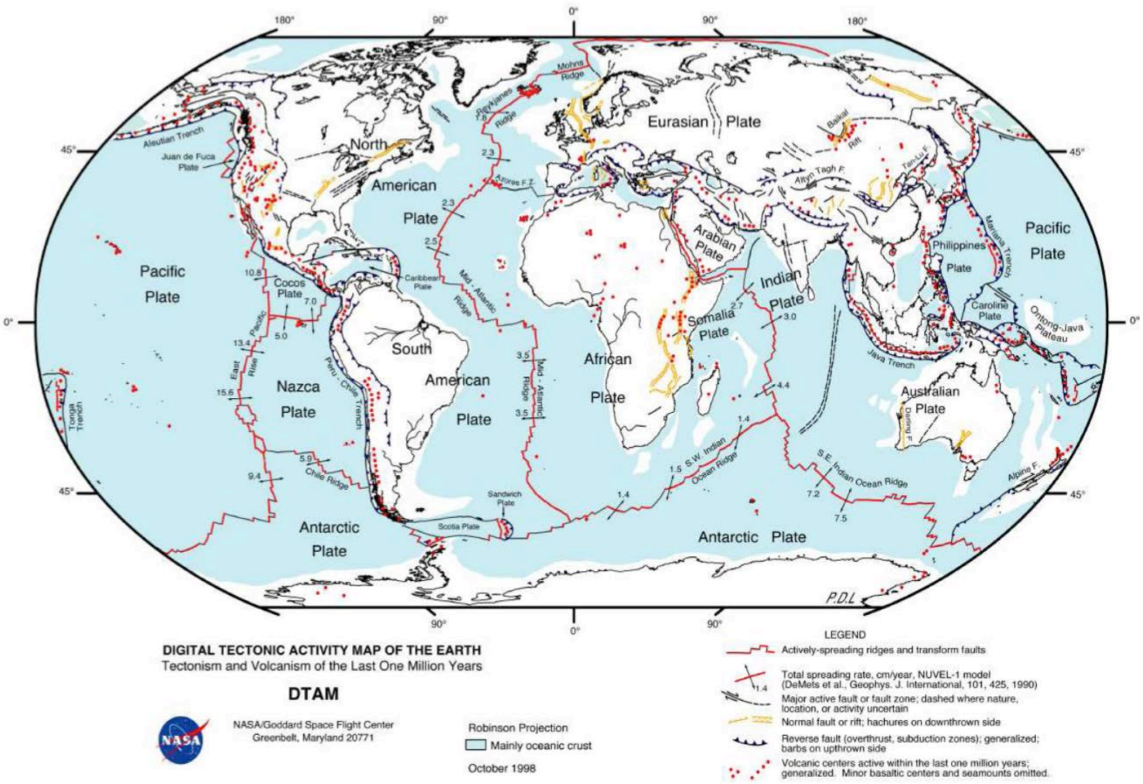

FIGURE 3. PLATE TECTONIC MAP OF THE WORLD, FROM NASA GODDARD SPACE FLIGHT CENTER.

The plates are rigid blocks composed of Earth's crust and uppermost mantle (often referred to as 'lithosphere'), whose movement governs the global distribution of earthquakes. Their movement is a manifestation of convection, or thermal transfer of heat, within a more plastic layer underlying the lithosphere within Earth's mantle, the asthenosphere. The fundamental axiom of plate tectonics is that the tectonic plates are internally rigid, and thus experience little internal deformation, but are in constant motion with respect to one another. Thus, the highest rates of active deformation—and consequently the majority of the world's earthquake activity—take place along the boundaries of the tectonic plates.

Earth's plate boundaries can be classified according to the relative motion that occurs along them (Figure 4). Thus, plate boundaries can be categorized as convergent, divergent, or transform, depending on whether their relative movement brings two plates closer, apart, or sliding laterally past one another. Plate boundaries are further classified depending on the type of crust involved in the plate boundary interaction, continental or oceanic. At divergent plate boundaries, new lithosphere is created as molten rock from Earth's mantle wells up to the surface, where it spreads, cools and forms new rock, and plates move laterally away from the upwelling zone. A continental rift zone is formed where the plate divergence occurs beneath a continent. The rift eventually will evolve into an ocean basin separating the continents on either side of the rift. Prominent examples include the East African Rift and the Baikal Rift of central Russia. If the plates adjoining the divergent margin are oceanic, the boundary is called a mid-ocean ridge (or oceanic spreading center), which forms new oceanic plates symmetrically about the rift zone. Prominent examples include the mid-Atlantic Ridge and the East Pacific Rise.

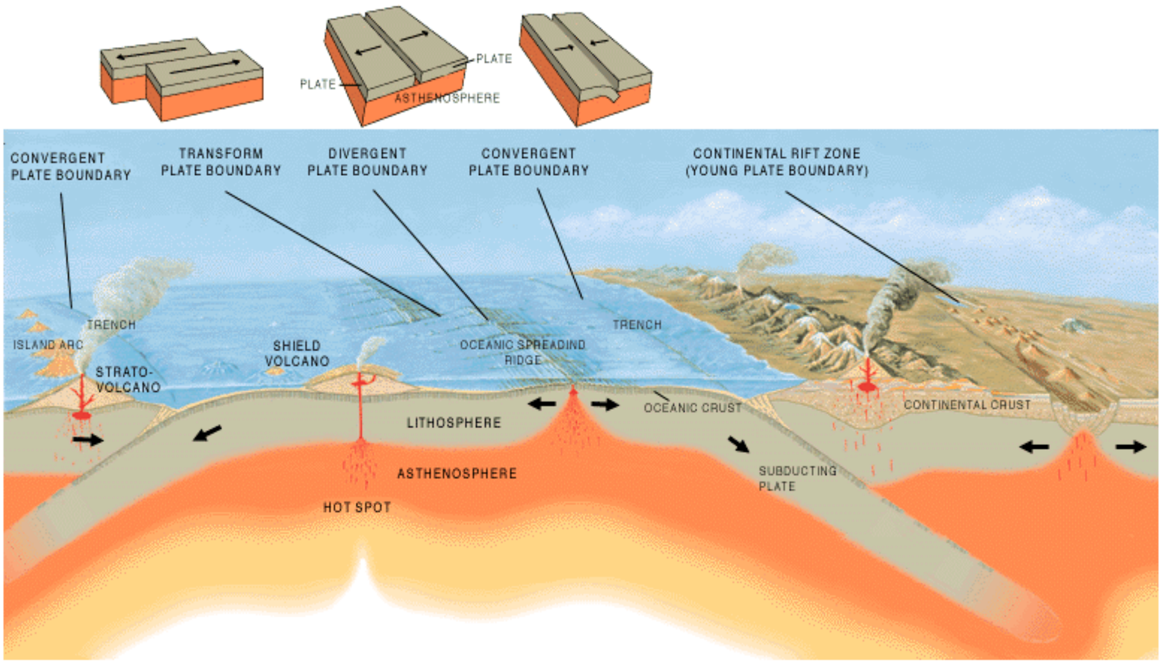

FIGURE 4. DIAGRAM OF PLATE TECTONIC PROCESSES, FROM KIOUS AND TILLING (2009).

At convergent plate boundaries, older, dense lithosphere is consumed, as the rocks that form the bottom of the ocean slide under lighter continental rocks they are heated and compressed and eventually mix into the Earth's mantle, where it is recycled in the process of mantle convection. Where one of the two converging plates is oceanic, it takes the form of a subduction zone, marked by a deep-sea trench, a line of active volcanism, and intense earthquake activity, extending from Earth's surface to depths as great as 700 km. Where both plates are oceanic, a volcanic 'island arc' is formed on the overlying plate, and earthquake activity follows an inclined seismic zone marking the trajectory of the subducting lithospheric plate. Examples include the Philippine and Indonesian archipelagos. Where one plate is oceanic and the other is continental, the oceanic plate is thrust beneath the continental margin, marked by a deep-sea trench, intense earthquake activity, and a volcanic mountain chain. The Andes of South America and the Cascade Range of North America are examples of such continental subduction zones. Where both converging plates are composed of continental crust, neither plate has sufficient density to be carried back into Earth's mantle, and a continental collision results. Such zones are characterized by high relief, active deformation and intense earthquake activity. Within the APEC region, the mountains of Taiwan are an example of a zone created by an initial stage of continental collision.

Finally, at transform plate boundaries, lithosphere is neither created nor consumed, and neighboring plates slide laterally past one another. Transform faults are a common component of oceanic spreading centers, manifesting as oceanic fracture zones, sharp lateral discontinuities in the mid-oceanic ridge system. In continental zones, transform faults take the form of elongated continental fault systems known as transcurrent or strike-slip faults. Such faults can occur as the principal component of a transform plate boundary—such as the San Andreas Fault of the western United States, the Alpine Fault of New Zealand, or the Queen Charlotte-Fairweather Fault system of Canada. In some cases, they can be a subsidiary component of a convergent plate boundary, such as the Sumatra Fault of Indonesia, the Altyn Tagh Fault of China, or the Philippine Fault.

Of course, the plate theory is a simplification of the actual patterns of seismicity and Earth deformation. First, we recognize that along some of Earth's tectonic boundaries, the zone of plate boundary deformation may extend for hundreds or even thousands of kilometers, and thus the concept of a simple 'plate boundary' is not sufficient to characterize completely the behavior of the zone intervening between plates. Thus, we now think in terms of 'plate boundary zones', areas of more intensive deformation that separate the largely rigid interiors of the Earth's major lithospheric plates (Figure 5).

On closer examination, these plate boundary zones are often found to be composed of smaller blocks of Earth's crust, known simply as 'blocks' or 'microplates', which are identified as relatively stable zones surrounded by belts of deformation and earthquake activity (Figure 6). Second, we recognize that a small but significant number of earthquakes occur at great distances from plate boundaries, and are best described as 'intraplate earthquakes', which must occur due to geological stresses accumulating deep in the interior of plates. Examples of such intraplate earthquakes are the M7.2 1929 Grand Banks, Newfoundland (Canada) earthquake, the 1811-1812 sequence of three major (M~7) earthquakes in New Madrid, Missouri (central United States), and the M7.7 2001 Bhuj earthquake in Gujarat Province, India.

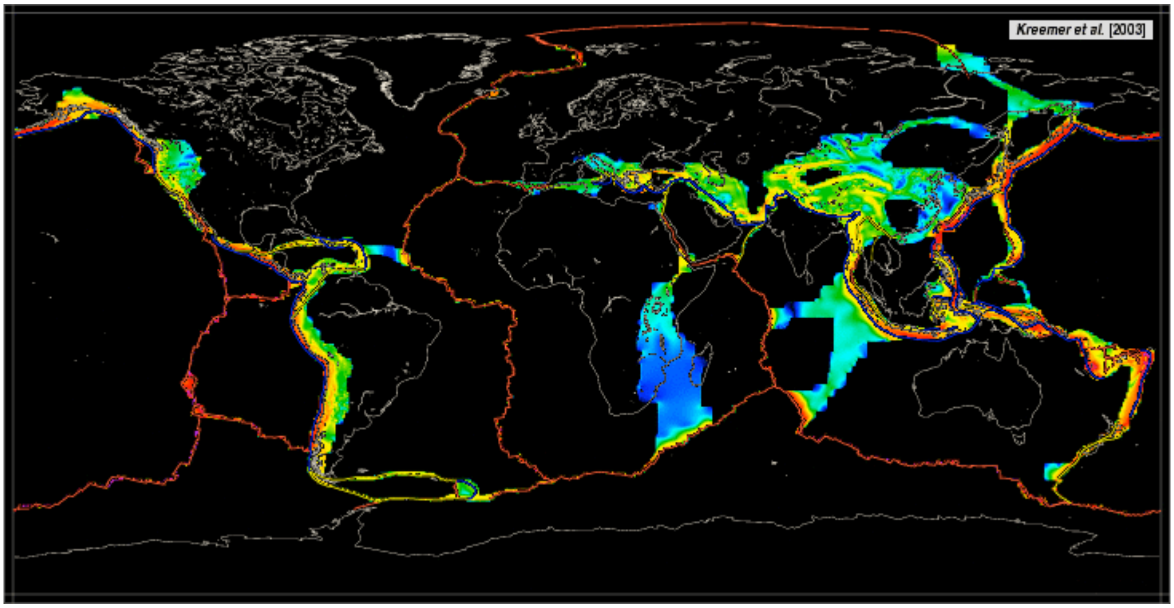

FIGURE 5. GLOBAL MAP OF CRUSTAL DEFORMATION RATES, ESTIMATED BY KREEMER ET AL. (2003). WARMER AND COOLER COLORS REPRESENT HIGHER AND LOWER DEFORMATION RATES, RESPECTIVELY. BLACK AREAS REPRESENT TECTONICALLY STABLE AREAS (PLATES).

Seismotectonic Constraints on Earthquake Behavior

The seismotectonic setting places important constraints on the potential size, distribution, and frequency of occurrence of major, destructive earthquakes. It also affects in a profound way the characteristics of wave propagation that influence the distribution of earthquake-related damage and secondary effects triggered by the earthquake.

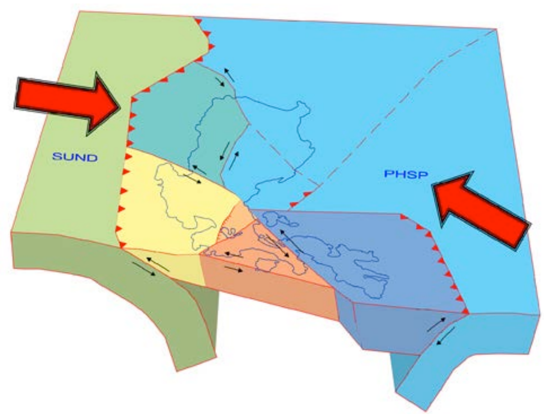

FIGURE 6. EXAMPLE OF MICROPLATE (OR BLOCK) TECTONICS IN A PLATE BOUNDARY ZONE IN THE PHILIPPINE ARCHIPELAGO. FROM HAMBURGER ET AL. (2010).

The spatial and temporal distribution of earthquakes, or seismicity, of an area is controlled largely by the nature of Earth deformation and the distribution of earthquake-generating structures in the region. Since the pioneering work of geologists G.K. Gilbert and H.F. Reid, in the aftermath of the devastating 1906 earthquake in San Francisco, there has been widespread recognition of the fundamental connection between geologic faults and distribution of earthquakes. They first recognized that the catastrophic release of energy associated with the 1906 earthquake was associated with a 475 km-long rupture in the Earth's crust, along the San Andreas Fault. Their work led to a theory that explained the connection between plate tectonics and the cyclical generation of earthquakes of faults like the San Andreas.

These observations led to Reid's development of the elastic rebound theory, which suggested a mechanism by which the slow accumulation of tectonic strain along active faults might manifest itself in cyclical earthquakes. The theory, illustrated in Figure 7, suggests that the slow relative movement between tectonic plates, at rates of several millimeters per year, results in the gradual deformation of the rocks adjoining the plate boundary. This process of elastic strain accumulation stores tectonic energy in the rocks adjoining an active fault. As the blocks continue to deform, the forces acting on the fault gradually increase, until they exceed the breaking strength of the fault. At that time, the fault suddenly ruptures, and the rocks on either side of the fault return to their original (undeformed) state. It is this sudden 'rebound' of the rock that provides the energy released in a large earthquake. Reid's theory remains the fundamental model describing the earthquake cycle. We now recognize that it is the relative motion between plates that manifests itself in a series of fault ruptures along Earth's plate boundaries. The location of major ruptures along the Pacific-North American plate boundary in the western United States is shown in Figure 8.

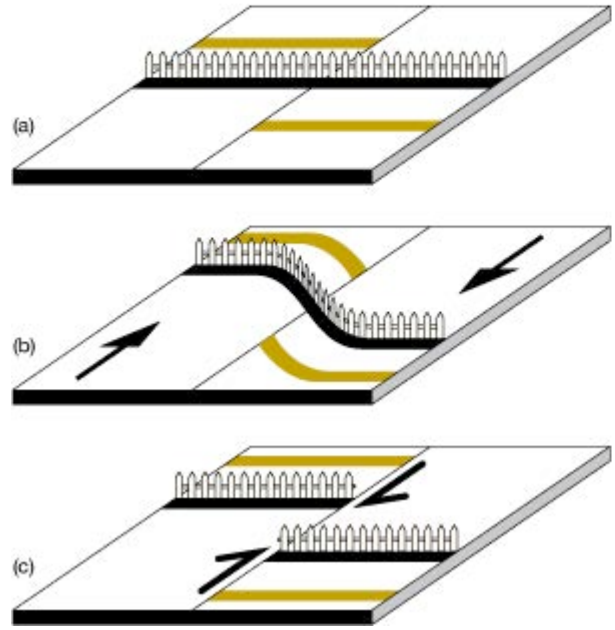

FIGURE 7. SCHEMATIC ILLUSTRATION OF THE ELASTIC REBOUND THEORY, FROM THE IRIS CONSORTIUM (HTTP://WWW.IRIS.EDU/HQ/GALLERY/PHOTO/1530).

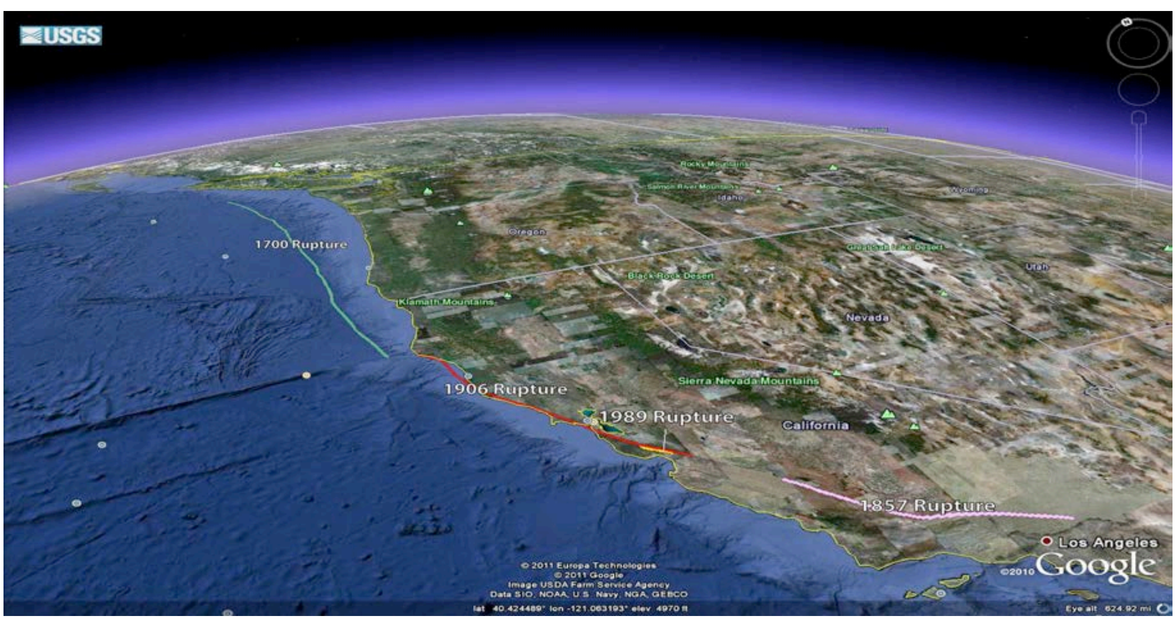

FIGURE 8. RUPTURE ZONES OF MAJOR EARTHQUAKES ALONG THE WESTERN BOUNDARY OF THE NORTH AMERICAN PLATE. HTTP://EARTHQUAKE.USGS.GOV/REGIONAL/NCA/VIRTUALTOUR/GLOBAL.PHP

Earthquake location and depth distribution of earthquakes play a fundamental role in controlling earthquake damage. The closer an earthquake is to a populated area, the higher the potential for damage. Earthquake depth can also play an important role in the damage associated with earthquake shaking. For a given size earthquake, shallow earthquakes tend to produce stronger shaking in more localized area; deeper events produce weaker shaking in the epicentral area, but distributed over a larger distance.

Along most plate boundaries, earthquake depths are limited to the upper 15-20 km beneath Earth's surface (e.g., Figure 9). This limitation occurs because of the characteristics of Earth deformation. At relatively shallow depths, where the Earth's crust is relatively cool, the elastic rebound theory holds that the rocks are able to accumulate stress along locked fault zones until the stress can be relieved in a major earthquake. At greater depths, the Earth's crust behaves quite differently; increased temperature and pressure leads to more 'plastic' behavior, whereby rocks are able to deform permanently without fracturing.

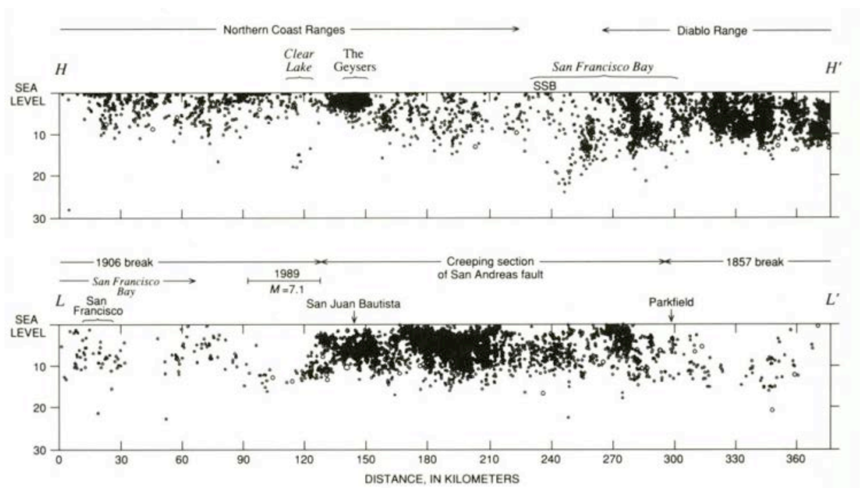

FIGURE 9. CROSS SECTIONS ALONG THE SAN ANDREAS FAULT SYSTEM IN NORTHERN AND CENTRAL CALIFORNIA. VERTICAL AXIS SHOWS DEPTH IN KM. FROM HILL ET AL. (1990).

The exception to this rule occurs in subduction zones, where earthquakes occurring within the down-going lithospheric plate can take place at depths from tens to hundreds of km beneath Earth's surface. These intermediate-depth (70-300 km) and deep (300-700 km) earthquakes typically form a well-defined inclined seismic zone that marks the position of the subducting slab, as illustrated in Figure 10. If large enough and close enough to Earth's surface, these 'intraslab earthquakes' can produce significant impacts at Earth's surface.

Along an active convergent plate boundary, such as the subduction zone illustrated in Figure 11, earthquakes can occur in a number of neighboring tectonic environments. In the Cascadia subduction zone offshore western North America, offshore earthquakes frequently occur in conjunction with the spreading center/ transform fault system of the Pacific-Juan de Fuca plate boundary. Earthquakes can occur close to or seaward of the trench that marks the boundary between the subducting Juan de Fuca and overlying North

American plates. These intraplate events are often associated with bending of the downgoing plate as it approaches the subduction zone.

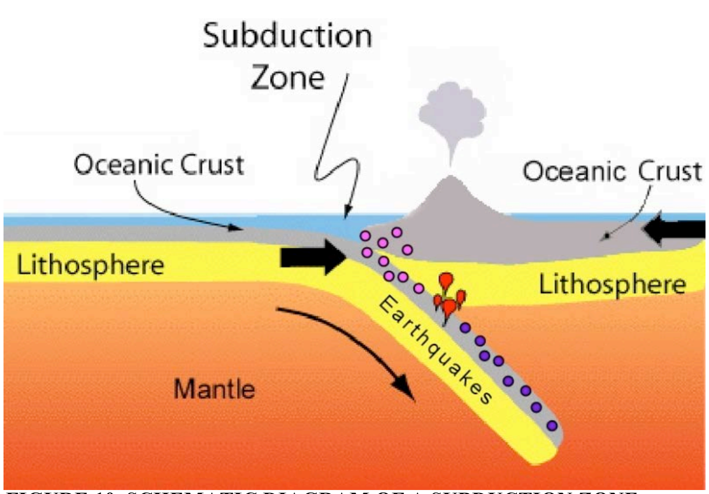

FIGURE 10. SCHEMATIC DIAGRAM OF A SUBDUCTION ZONE ILLUSTRATING THE WADATI-BENIOFF ZONE MARKING THE TRAJECTORY OF THE SUBDUCTING PLATE. FROM HTTP://WWW.GEO.CORNELL.EDU.

The largest and most destructive events are frequently those that occur along the subduction interface itself, typically located at depths of 15-30 km, just offshore or close to the coast. It is these 'subduction megathrust' earthquakes that comprise most of the world's 'great earthquakes' with magnitudes >8. Recent examples of such megathrust earthquakes are the 2004 Sumatra earthquake, the 2010 Maule, Chile earthquake and the 2011 Tohoku, Japan earthquake. The sudden rebound associated with these rare great earthquakes can trigger large tsunamis as the sea floor above the earthquake epicenter lurches forward with displacements as great as several tens of meters. Intraplate earthquakes can also occur within the upper plate of the subduction zone, either close to or landward of the active volcanic arc. These upper plate 'crustal earthquakes' tend to be smaller and less frequent than the subduction zone events, but because of their proximity to populated areas, can be equally destructive.

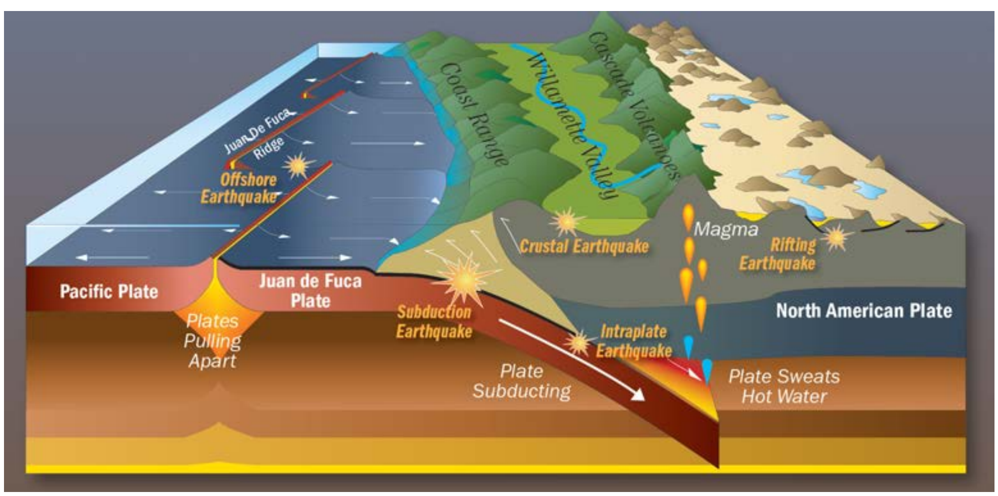

FIGURE 11. SCHEMATIC DIAGRAM SHOWING PLATE TECTONIC STRUCTURES ASSOCIATED WITH THE CASCADIA SUBDUCTION ZONE ALONG THE OREGON COAST OF THE WESTERN UNITED STATES. FROM LILLIE ET AL. (2009).

Elements of Seismic Risk: A Primer on Natural Hazards and Seismic Risk

Earthquakes represent one of a suite of natural hazards that have potential to produce devastating human impacts. They are products of Earth's natural processes intersecting with the physical and social infrastructure that characterize human societies. Schools, as critical elements in every society, are of particular concern to most citizens. Understanding seismic risk to schools is the first step in understanding how to reduce risk and manage such threats. Fortunately, established techniques exist to quantify risk and to use the information to help determine what should be done and to establish priorities.

Natural hazards are defined as relatively rapid-onset natural phenomena (to distinguish them from long-acting phenomena such as climate change or drought) that have the potential to produce devastating human impact. The concept of a hazard emphasizes the potential for such human impact, independent of its actual effects; vulnerability describes the degree to which a given population is exposed to impacts of natural hazards; and risk represents the degree to which a given population might be affected by a given type of hazard, i.e. the combined effect of hazard and vulnerability.

The concept of a *natural disaster* denotes a crisis situation causing widespread damage that exceeds our ability to respond and recover. Seismic *risk assessment* involves quantitative evaluation of the probability of a given population being affected by an earthquake. The concept of *resilience*, adopted from the field of ecology, refers to the ability of a society to resist or recover from the impacts of a natural hazard. Finally, the concept of *risk mitigation* represents processes by which the risk of future disasters is eliminated or reduced. The focus of this paper is to describe geologic principles that can help APEC economies to assess the vulnerability of one specific element of our society, our schools, to a few specific types of natural hazards. With an assessment in hand, economies can seek the most effective approaches to mitigate the potentially devastating impacts of future natural disasters.

Earthquake risk mitigation relies on high-quality scientific and technical work that establishes both the potential for future disasters (probabilistic seismic hazard assessment), the vulnerability to its impacts (seismic vulnerability assessment) and identifies processes by which risks can be minimized—ranging from long-term approaches like land-use planning and building codes to short-term disaster response and post-event reconstruction.

A first step to reducing risk is to assess seismic hazards facing a region. Following Hays (1980), the process of seismic hazard assessment for a particular site can be broken down into the following discrete steps:

1. Identification of geological structures with the potential to generate earthquakes;
2. Determination of the past record of earthquake activity in the region (including historic and prehistoric events);

3. Assessment of the probability of future earthquakes occurring on the suite of earthquake source zones that might affect a particular site;
4. Definition of the characteristics of seismic wave propagation and attenuation (or absorption) of seismic energy;
5. Determination of earthquake-induced ground motions expected at the site, based on the potential earthquake sources and patterns of regional seismic wave propagation;
6. Determination of local ground response, as affected by local-scale geology, topography, soil conditions, etc.; and
7. Evaluation of uncertainties in the ground-motion design variables.

Analysis of earthquake hazards often includes the wide range of secondary effects that may be triggered by earthquakes. These include ground failure, such as landslides, mudflows, and liquefaction, tsunamis, flooding, fires, and widespread impacts on human infrastructure, such as building collapse, impacts on power, transportation, communication, water, and sewer systems.

Although geologists can readily identify where the most active large faults are located, it is not possible to determine when earthquakes will occur with enough precision to be reliable. Because there remains considerable uncertainty in estimating future magnitude, location and time, the practice is to use statistics, or probability theory, to describe the hazard. This approach, known as probabilistic seismic hazard assessment, focuses on the potential for earthquake-related damage to vulnerable populations in a given area. The approach seeks to assess the integrated probabilities of all possible earthquakes that might affect the site. In order to assess these probabilities, geoscientists must gather the relevant information on all of the earthquake-generating faults in the vicinity of the site. Most of the damage associated from earthquakes results from shaking. Because shaking is caused by from seismic waves, damage assessments rely on detailed information on the characteristics of seismic wave propagation between each of the possible seismic sources and the area of interest. The probabilities of strong ground motion associated with each of the sources are summed and presented in the form of the level of ground motion with a certain probability of occurrence.

Seismic hazard is often presented in the form of a seismic hazard map, which typically express earthquake hazard in the form of estimated probability of strong ground shaking expected within a given time interval (e.g., 50 or 100 years). Maps of seismic hazard are typically generated on a country-by-country basis, with somewhat divergent approaches to estimating hazard based on different types of observational data and earthquake source models. Several global initiatives have sought to integrate these national or regional earthquake hazard assessments into a comprehensive global frame. Notable among these are the Global Seismic Hazard Assessment Program (GSHAP), a demonstration project of the United Nations International Decade of Natural Disaster Reduction (http://www.seismo.ethz.ch/static/GSHAP/), and the more recent Global Earthquake Model (GEM) initiative (http://www.globalquakemodel.org/). An example of the global seismic hazard map produced by the GSHAP initiative (Giardini et al., 1999) is shown in Figure 12. The warmer colors on the map represent areas of higher probability of experiencing damaging earthquakes in the next half-century. It is worth noting that a significant proportion of the APEC region occupies areas of the map that are denoted by red colors, i.e., areas of high seismic hazard. This is particularly true for the economies surrounding the circum-Pacific 'Ring of Fire.'

Faulting and Earthquake Hazard

Based on the connection between earthquake generation and active faults, we recognize that the distribution of earthquakes is governed by the distribution of these "seismogenic faults". Likewise, their magnitude is controlled by the potential fault area—and the accumulated stresses—that might be released in a given earthquake rupture. In general, the size (or magnitude) of earthquakes varies logarithmically as a function of the rupture length (or similarly, area) of the fault rupture. That is, each increment of a unit of earthquake magnitude is equivalent to approximately a factor of ten increase in the fault rupture length. Thus, an earthquake of magnitude 5 might be triggered by a fault rupture of several km length (~10 km^2 rupture area), magnitude 6 by ~10 km rupture length (~100 km^2 area) and magnitude 7 by ~100 km length and 1000 km^2 area. The great (M9.0+) earthquakes that struck Indonesia in 2004 and Japan in 2011 had rupture areas of 1300x160 km (300,000 km^2) and 300x150 km (50,000 km^2), respectively.

The fault area that might rupture in a given earthquake is in turn controlled by the geometry of the fault. Thus, the behavior of a fault is limited by geometric or geological discontinuities along its length—such as bends or breaks in the fault's trace—and by the upper and lower depths at which the fault can be locked by frictional strength. In most areas of the Earth, the depths of earthquakes signal the range of depths at which this frictional (or elastic) properties of rock permit the accumulation of elastic strain. These 'locking depths' can also be determined through the application of precise surveying methods, most commonly using the Global Positioning System (GPS). These precise surveying measurements can be used to identify areas of the fault that are freely slipping—and thus, not accumulating strain—versus those that are locked and storing elastic strain for future earthquakes, as illustrated for a segment of the San Andreas Fault in Figure 13. Ultimately, it is that stored elastic strain that provides the energy released in future earthquakes.

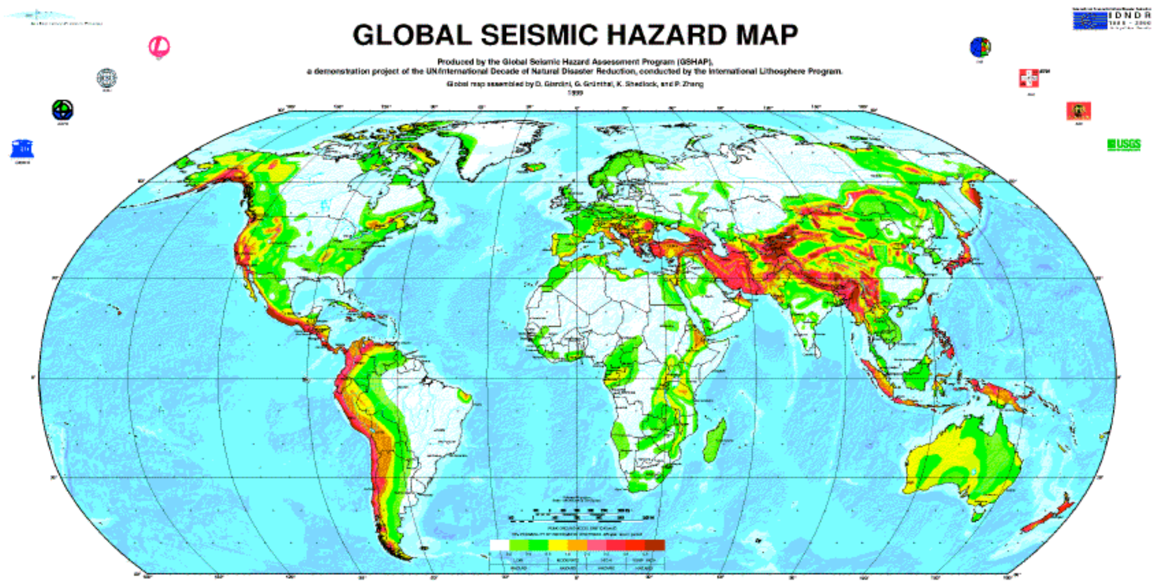

FIGURE 12. GLOBAL SEISMIC HAZARD MAP, FROM GIARDINI ET AL. (1999).

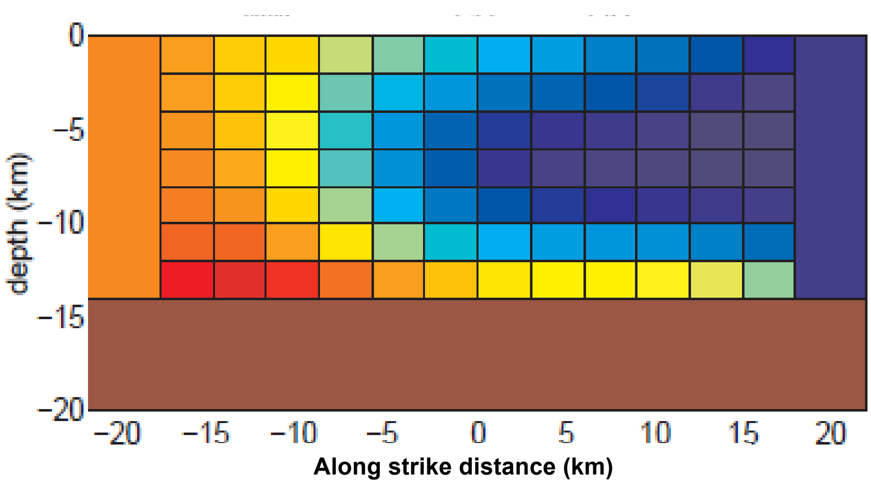

FIGURE 13. IMAGE OF SLIP ACCUMULATION ALONG A SEGMENT OF THE SAN ANDREAS FAULT, BASED ON PRECISE GPS MEASUREMENTS AT EARTH'S SURFACE. AREAS IN WARMER COLORS ARE SLIPPING, AT RATES OF 20-35 MM/YR, WHILE THOSE IN COOLER COLORS ARE RELATIVELY LOCKED, AND THUS ACCUMULATING ELASTIC STRAIN. FROM MURRAY ET AL (2001).

Wave Propagation and Earthquake Hazard

The degree of shaking experienced by a site is largely a product of the size of the earthquake—quantified by the source magnitude—and the distance of a given site from the earthquake source. The expected shaking, usually in the form of ground acceleration, is presented as a function of distance from the source, in the form of regional attenuation relations. An example, from the central United States, is illustrated in Figure 14.

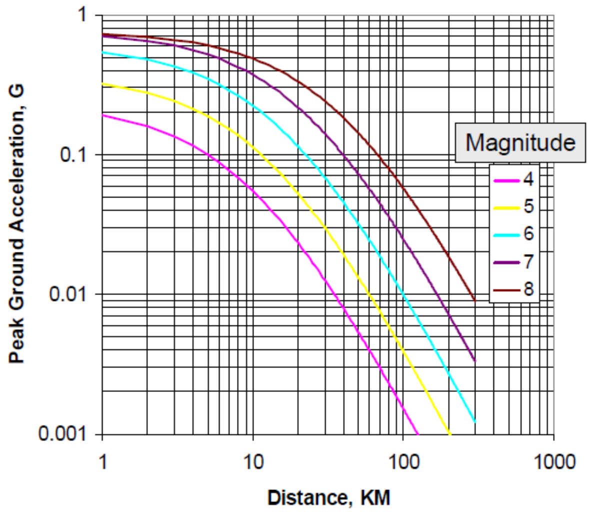

FIGURE 14. ESTIMATES OF ATTENUATION RELATIONS FOR THE CENTRAL UNITED STATES. FIGURE ABOVE SHOWS DECAY OF ACCELERATION AS A FUNCTION OF DISTANCE FOR EARTHQUAKES AT A RANGE OF MAGNITUDES. ATTENUATION RELATIONS FROM SADIGH ET AL. (1997); FIGURE FROM FEMA (2003).

Zones of recent tectonic and volcanic activity—typically those close to plate boundaries—tend to produce zones of higher seismic attenuation (thus, lower seismic amplitudes) than those associated with older and more strongly consolidated continental crust. A well-known example involves the comparison between observed ground motions in the eastern and central US versus those in the western United States. There, amplitudes of ground motion can differ by more than a factor of ten, due simply to this difference in the character of wave propagation.

In addition to the regional characteristics of seismic wave propagation, there is strong variability in the behavior of seismic waves as they interact with topography and geological materials near Earth's surface. These 'site effects' can cause significant attenuation (absorption) of seismic waves, or they can be amplified to produce significantly stronger shaking. The presence of thick, unconsolidated soils can amplify ground accelerations by more than a factor of 2, as illustrated in Figure 15. A well-known example of this seismic amplification was associated with the 1985 Mexico City earthquake, whereby the thick unconsolidated lake sediments underlying Mexico City served to amplify the seismic waves in a limited area of downtown Mexico City—thus producing a zone of significant earthquake damage far from the earthquake source. The process of identifying areas subject to variable strong ground shaking effects

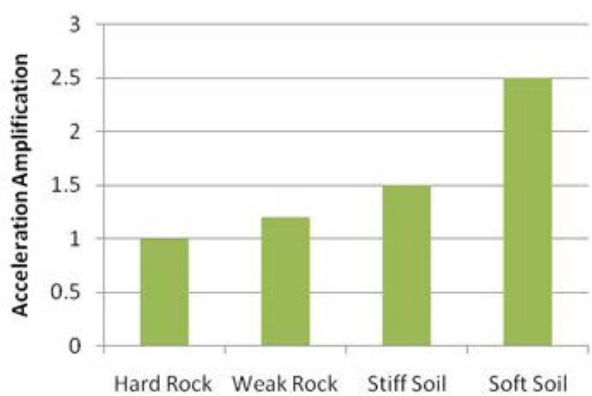

FIGURE 15. AVERAGE ACCELERATION AMPLIFICATION AT SAN FRANCISCO BAY AREA SITES COMPARED TO ADJACENT BEDROCK SITES. FIGURE FROM MAHDYIAR AND BAZZURO (2009).

associated with site conditions is referred to as seismic microzonation. This application of engineering seismology has been applied extensively to major urban areas subject to earthquake shaking.

Secondary Effects of Earthquakes

Some of the most severe impacts of earthquakes are *not* those directly produced by the ground shaking associated with seismic waves; rather, they are associated with a wide range of secondary effects that earthquakes can trigger. These include aftershocks, earth movements (landslides, rockfalls, avalanches, mudflows), surface rupture, liquefaction and tsunamis. The frequency of occurrence of these events is highly dependent on the magnitude of the earthquake and on the local geological and topographic conditions surrounding the earthquake epicenter. Table 2 summarizes the relative frequency of these events. Other secondary effects, such as fires, flooding, or structural collapse, are commonly associated with the intersection of earthquake-related shaking and human infrastructure, such as gas and water mains, dams, levees, and sewer systems.

TABLE 2. RELATIVE FREQUENCY OF OCCURRENCE OF SECONDARY EFFECTS OF EARTHQUAKES. MODIFIED FROM RANGUELOV (2003).

Earthquake Magnitude	Aftershocks	Landslides	Rockfalls	Avalanches	Liquefaction	Surface Rupture	Tsunami*
3-4	Occasionally	Very rare	Very rare	Very rare	Never	Never	Never
4-5	Frequently	Rare	Very rare	Very rare	Never	Never	Never
5-6	Always	Occasionally	Rare	Rare	Occasionally	Very rare	Very rare
6-7	Always	Frequently	Frequently	Frequently	Frequently	Frequently	Occasionally
7-8	Always	Always	Frequently	Frequently	Always	Frequently	Frequently*

**Tsunami occurrence is strongly dependent on the offshore location and depth of the earthquake source.*

Seismotectonic Summary of the APEC Region

Appendix A presents a detailed seismotectonic summary of each of the plate boundary zones comprising the APEC region. In the introductory section, we briefly summarize the seismotectonic attributes of the plate boundaries affecting each of the APEC economies, including information on tectonic plate interaction, active faults, and historical seismicity for the regions. The Appendix also presents a series of seismotectonic maps, developed by the United States Geological Survey's National Earthquake Information Center. These maps provide an excellent summary of the tectonic setting, historical earthquakes, present-day seismicity, and seismic hazard for much of the Asia-Pacific region. Appendix B presents a tabular summary of the major earthquakes affecting each of the APEC economies, including both large-magnitude and destructive earthquakes since 1900. The source is the USGS PAGER (Prompt Assessment for Global Earthquake Response) catalog (Allen et al., 2009).

Conclusions

This paper has examined the seismological and tectonic framework that provides a context for understanding earthquake hazards to schools in the Asia-Pacific region. Because we cannot predict the exact time and location of future earthquakes, we must rely on a probabilistic approach, which takes into account the suite of possible sources of earthquakes, the range of possible sizes of earthquake, estimate their frequency of occurrence, and assess their potential impact on APEC economies and the social and human infrastructure of each economy. When earthquakes occur, their actual impact depends strongly on the degree to which individual economies have prepared for natural hazards. The field of risk mitigation provides a suite of mechanisms that allow societies to reduce vulnerability and thereby reduce the impact of future events.

Although this represents a very cursory overview of a very broad and complex field, it is worth summarizing a number of our key conclusions:

1. Earthquakes are an inevitable consequence of life on a dynamic planet. They cannot be prevented, but their impacts can be reduced through conscientious efforts in advance of future earthquakes.

2. Earthquake activity is a manifestation of the movement and interaction of tectonic plates. Earthquakes are primarily generated near the boundaries of tectonic plates, where they converge, diverge, or slide laterally past one another.

3. Earthquakes can also occur within plates, but less frequently, and typically of smaller magnitude.

4. It is this motion of Earth's tectonic plates that applies forces to the Earth's crust in the vicinity of active faults. It is the cyclical accumulation and release of these tectonic stresses along faults that results in cycles of earthquake activity.

5. The potential impact of earthquakes depends strongly on the size and location of the earthquake source, the propagation of seismic waves from the source, and the nature of the soils in the vicinity of a given site, which can serve to amplify or attenuate the seismic wave energy.

6. The impact of an earthquake may be strongly enhanced by the occurrence of secondary effects, including aftershocks, rockfalls, landslides, liquefaction, surface rupture and tsunamis.

7. Other secondary effects, such as fires, flooding, or structural collapse, are commonly associated with the impacts of earthquake-related shaking on human infrastructure, such as gas and water

mains, dams, levees, and sewer systems.

8. Because much of the APEC region is distributed around the rim of the Pacific Ocean basin, it also coincides with areas of high seismic activity and hence high seismic hazard. Areas of highest earthquake potential are commonly associated with convergent plate boundaries—notably the west coast of south and central America, the Pacific coast of Alaska, the northwestern United States and southwestern Canada, the Kuril-Kamchatka, Japan, Philippine, New Zealand, and Indonesian subduction zones, collisional plate boundaries along in China and Taiwan, and transform boundaries in the western United States and Canada.

9. Because of their high value to society, schools are ideal targets for risk mitigation activities. They can serve as linkages with social and economic networks in APEC communities, and are ideally situated to help communicate scientific knowledge to communities in need of enhanced knowledge of earthquake hazards.

Acknowledgments

I am particularly grateful to Harley Benz and colleagues at the National Earthquake Information Center, who provided seismotectonic maps that are included as part of Appendix A. Cheyne Geverd, Anna Nowicki, and Jeremy Maurer provided important contributions to data compilation and analysis. The manuscript was improved by constructive comments from Brian Tucker and Thomas Tobin of GeoHazards International. Kristen Yawitz of GHI provided editorial support. Partial funding for this project was provided by the United States Department of State, managed through a grant from the United States Geological Survey.

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Appendix A: Introduction to Seismotectonic Atlas of the APEC Region

This appendix presents a region-by-region seismotectonic summary. The summaries are accompanied by a new series of maps, developed by the U.S. Geological Survey's National Earthquake Information Center. These maps summarize the tectonic setting, historical earthquakes, present-day seismicity, and seismic hazard for much of the Asia-Pacific region. In this section, we briefly summarize the seismotectonic attributes of the plate boundaries affecting each of the APEC economies.

1. South America (Peru, Chile): Plate A1

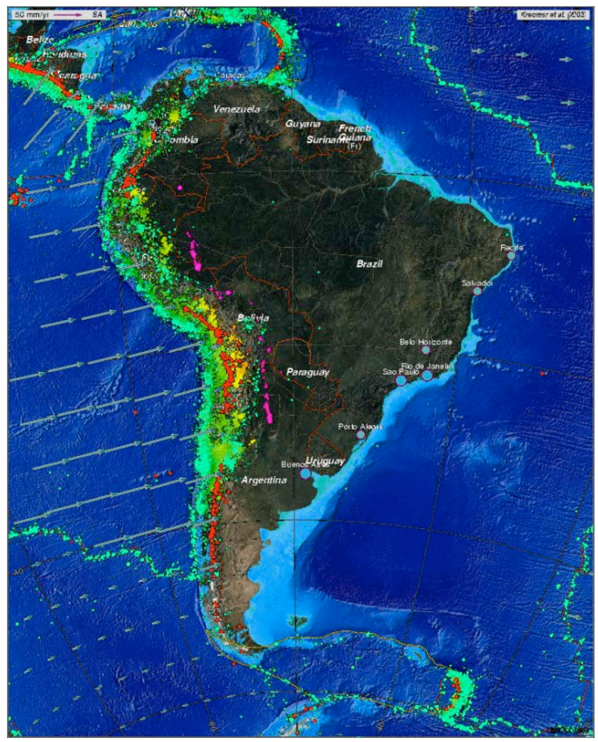


FIGURE A1. SEISMOTECTONIC SETTING OF SOUTH AMERICA, SUPERIMPOSED ON 'FACE OF THE EARTH' SATELLITE IMAGERY AND SEA-FLOOR BATHYMETRY. EARTHQUAKES ARE SHOWN BY COLORED SYMBOLS WITH WARMER COLORS REPRESENTING INTERMEDIATE AND DEEP-FOCUS EARTHQUAKES. ACTIVE VOLCANOES ARE SHOWN BY RED TRIANGLES. MODEL PLATE MOTIONS, SHOWN WITH RESPECT TO SOUTH AMERICA, ARE FROM KREEMER ET AL. (2003).

The Peru-Chile Trench (Figure A1) marks the boundary between the Nazca and South American plates in the southeastern Pacific Ocean basin. It extends some 7000 km along the western margin of the South American continent, near the coastlines of Columbia, Ecuador, Peru, and Chile. The plate boundary is associated with near-orthogonal convergence at rates from 65 to nearly 80 mm/yr. South of the Chile Rise, the south American and Antarctic plates converge at a significantly lower rate, <20 mm/yr. The convergence is manifested in the form of uplift and deformation of the Andean Cordillera, and active volcanism associated with a chain of some 178 active volcanoes extending from Colombia to Chile. The plate boundary has been the site of over 24 great (M>7.8) earthquakes since 1900, including the M9.5 1960 Chile earthquake, the largest event in the instrumental record, and the M8.8 2010 Maule earthquake. Among the most destructive of these events have been earthquakes in Peru in 1970 (70,000 casualties), 1939 in Chile (28,000 casualties), and 1949 and 1987 in Ecuador (6,000 and 5,000 casualties, respectively). Among the major South American cities affected by the Nazca-South America seismic zone are Bogota, Colombia; Quito and Guayaquil, Ecuador; Lima and Arequipa, Peru; and Valparaiso, Santiago, and Concepcion, Chile.

Because the Nazca plate slides beneath the South American plate at a relatively shallow angle, it results in a plate interface that extends from the trench to the coastline. The geometry of this plate interface results in relatively strong frictional coupling between the two plates and in turn, relatively infrequent, high-magnitude plate boundary earthquakes. The largest events are those that occur along the subduction interface, with potential impacts on coastal communities and potential to trigger major, Pacific-wide tsunamis. Intraplate events can occur both in the downgoing Nazca plate and the overlying South American plate. Crustal events in the upper plate have the potential to trigger significant damage in localized areas in Peru and Chile. Upper plate events affect other South American economies, including Argentina, Bolivia, and Brazil. Intraslab events occur frequently at depths from several tens to hundreds of km depth, and usually have limited impact on population centers. The largest deep earthquake in recorded history was the M8.2 1994 Brazilian deep event (634 km depth), which resulted in 10 deaths and was felt throughout South America.

The highest risk areas are those situated near the coast and those near active crustal fault zones. The high topographic gradients and potential for strong ground shaking make the area vulnerable to landslides and other mass movements. Tsunami risk is of particular concern to coastal communities.

2. Mexico and Central America: Map A2

The high seismic activity of Mexico and Central America (Figure A2) is associated with the interaction between the North American plate and several smaller plates that surround it: the Pacific plate to the northwest, the Caribbean plate to the south, and the Cocos Plate (and its neighbor, the small 'Rivera plate') to the west. It is the convergent boundary between the Cocos and North American plates that produces the majority of the large earthquakes in the area. The Middle America Trench extends some 3000 km along the western margin of Central America, near the coastlines of Mexico, Guatemala, Nicaragua, El Salvador, Honduras, Costa Rica, and Panama. The plate boundary is associated with near-orthogonal convergence at rates from 17 to 60 mm/yr. The convergence is manifested in the form of uplift and deformation of the coastal mountains, and active volcanism associated with a chain of some 118 active volcanoes extending from central Mexico to Panama. The Trans-Mexican volcanic belt is home to nearly 40 active volcanoes. The plate boundary has been the site of 10 great (M>7.8) earthquakes

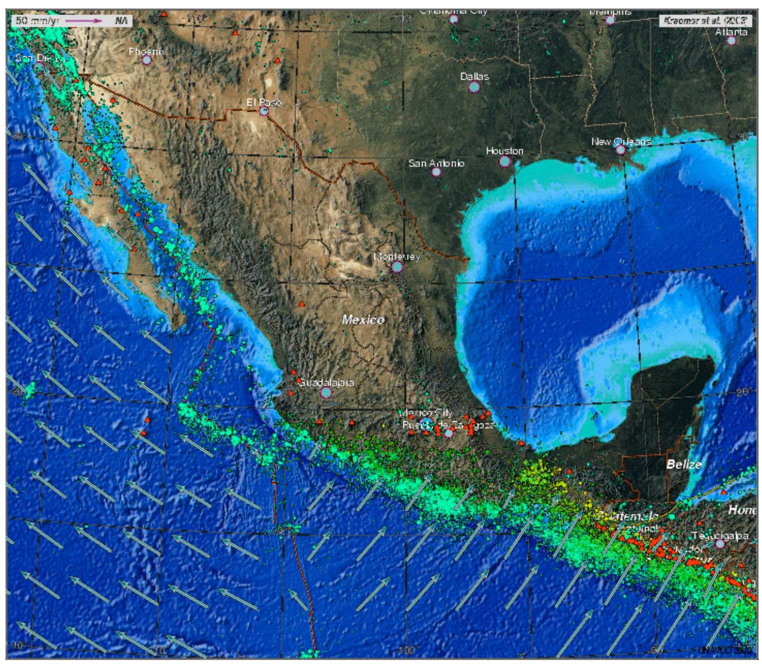


FIGURE A2. SEISMOTECTONIC SETTING OF MEXICO AND CENTRAL AMERICA. BASEMAP AND SYMBOLS AS IN FIGURE A1. MODEL PLATE MOTION ARE SHOWN WITH RESPECT TO NORTH AMERICA.

and nearly 100 large (M>7.0) earthquakes since 1900. The majority of these large events occurred along the Mexican segment of the plate boundary. Among the most destructive of these plate boundary earthquakes were the 1972 M6.2 Managua, Nicaragua earthquake (11,000 casualties), the 1976 M7.5 Guatemala earthquake (22,800 casualties), and the 1985 Mexico City earthquake (9,500 casualties). Among the major Central American cities affected by the Central American seismic zone are Guadalajara, Mexico City, and Morales, Mexico; Managua, Nicaragua, Guatemala City, Guatemala; San Salvador, El Salvador; and San Jose, Costa Rica. Coastal areas of northwestern Mexico and Baja California may also be affected by earthquakes associated with the rift-transform boundary in the Gulf of California. Coastal areas on the southwestern Pacific coast are at risk for local and regional tsunamis.

At the Middle America Trench, the down-going Cocos plate subducts along a relatively shallow plate interface that extends from the trench to the coastline. This shallow plate interface results in relatively strong frictional coupling between the two plates, resulting in a pattern of relatively infrequent, high-magnitude plate boundary earthquakes. The largest events are those that occur along the subduction interface, with potential impacts on coastal communities and potential to trigger major, regional tsunamis. Intraplate events can occur both in the downgoing Cocos plate and the overlying North American or Caribbean plates. Crustal events in the upper plate have the potential to trigger significant damage in localized areas in Mexico. Upper plate events affect other Central American economies, particularly El Salvador, Nicaragua, Honduras, Costa Rica and Panama. Intraslab events occur frequently at depths from several tens to hundreds of km depth, and usually have limited impact on population centers.

3. North America (United States, Canada, Mexico): Plate A3

The seismic activity of North America (Figure A3) affects the APEC economies of the United States, Canada, and Mexico. Seismicity is largely controlled by the relative plate motions between the North American plate and the neighboring Pacific, Juan de Fuca, and Cocos plates. The relative plate motions accommodated along this boundary include plate convergence along the Middle America Trench in Mexico, the Cascadia Trench on the U.S. Pacific northwest and southwestern Canadian coasts, and the Alaska-Aleutian subduction zone in Alaska; rifting and transform motion dominates along the Gulf of California; and transform motion takes place along the San Andreas Fault system in California and the Fairweather-Queen Charlotte Fault system in western Canada. Pacific-North American plate motions range from 50 mm/yr along the Gulf of California to 75 mm/yr along the Aleutian Trench. Relatively lower rates of convergence characterize the Cascadia subduction zone, where the Juan de Fuca plate (along with the Gorda and Explorer microplates) subducts obliquely beneath the North American plate at rates of 30-40 mm/yr. This 8000 km-long stretch of plate boundary results in a broad and complex zone of active seismicity and volcanism, including some 78 active volcanoes in the conterminous U.S. and 92 in Alaska.

The area of plate boundary interaction extends some 1000 km inboard from the plate boundary, and includes earthquakes, active faulting, and volcanism extending through the Basin and Range and Rocky Mountain provinces of the western U.S. and Canada, the

Colorado Plateau and Rio Grande Rift of the southwestern U.S. and Mexico, and deformation zones associated with the eastern California shear zone and the Yellowstone volcanic province. This plate boundary zone activity has resulted in a number of significant earthquakes, including the 1959 M7.3 Hebgen Lake earthquake in Montana, the 1954 M7.1 Fairview Peak-Dixie Valley earthquake in Nevada, the 1983 M6.9 Borah Peak earthquake in Idaho, and the 1972 M7.3 Landers, California earthquake.
The North America plate boundary zone has produced very high levels of seismic activity, including some 16 great (M>7.8) earthquakes and over 100 large (M>7) events. The vast majority of these events occurred within the Alaska-Aleutian plate boundary, with approximately four in Canada and sixteen in the coterminous United States. Among the most destructive events were the 1906 San Francisco earthquake (3000 casualties), the 1946 Fox Islands earthquake (165 casualties), and the 1971 San Fernando earthquake (64 casualties). More recent earthquakes in the San Francisco Bay area (M6.9 1989) and the Los Angeles area (Northridge M6.7 1994) produced significant numbers of casualties and an estimated $130B in economic losses.

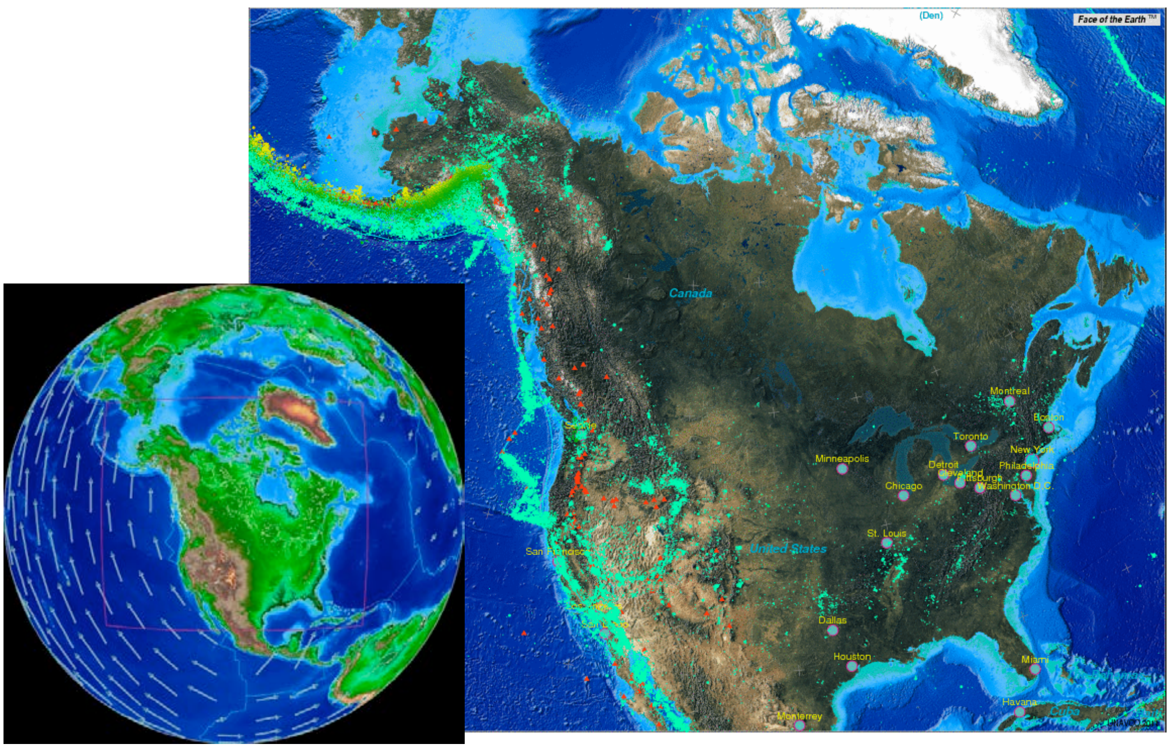


FIGURE A3. SEISMOTECTONIC SETTING OF THE NORTH AMERICAN PLATE. BASEMAP AND SYMBOLS AS IN FIGURE A1. INSET SHOWS MAP LOCATION WITH PLATE MOTIONS WITH RESPECT TO NORTH AMERICAN PLATE FROM KREEEMER ET AL. (2003).

As illustrated by the map in Figure A3, there has also been a significant amount of true intraplate seismic activity in both the United States and Canada, including the destructive 1811-12 New Madrid earthquake sequence (M7-7.5), 1929 Grand Banks, Newfoundland earthquake (M7.2), and the 1886 Charleston, South Carolina earthquake (M7.3).

Although the Cascadia subduction zone, located offshore the northwestern coast of the United States (near northern California, Oregon, and Washington) and Canada (southern

British Columbia), has not been associated with many destructive historical earthquakes, it is associated with a strongly frictionally coupled plate boundary, and thus a high risk for future large earthquakes. The prehistoric record suggests at least six large, prehistoric earthquakes, with recurrence times on the order of 300-600 years (Atwater et al., 2005). The most recent of these events was a great earthquake of 1700, whose magnitude is estimated at 8.7-9.2, whose timing and location was constrained by a tsunami recorded in Japan (Atwater et al., 2005).

The Alaska-Aleutian plate boundary is the site of the largest earthquakes, with potential to trigger major, Pacific-basin-wide tsunamis. It is dominated by plate subduction at rates ranging from 58 to 75 mm/yr and ranging from nearly orthogonal in southern Alaska to highly oblique in the western Aleutian Islands. To the east, the subduction of the Pacific plate gives way to arc-continent collision, where the Yakutat block converges with southeastern Alaska in the Wrangell-St. Elias region. The Alaska-Aleutian plate boundary is the site of 15 of the region's 16 great earthquakes, including the 1938 M8.6 Shumagin Islands earthquake, the 1946 M8.6 Unimak Island earthquake, the 1957 M8.6 Andreanof Islands earthquake, the 1964 M9.2 Prince William Sound (Anchorage) earthquake, and the 1965 M8.7 Rat Islands earthquake.

4. Kurile – Kamchatka (Russia, Japan): Plate A4

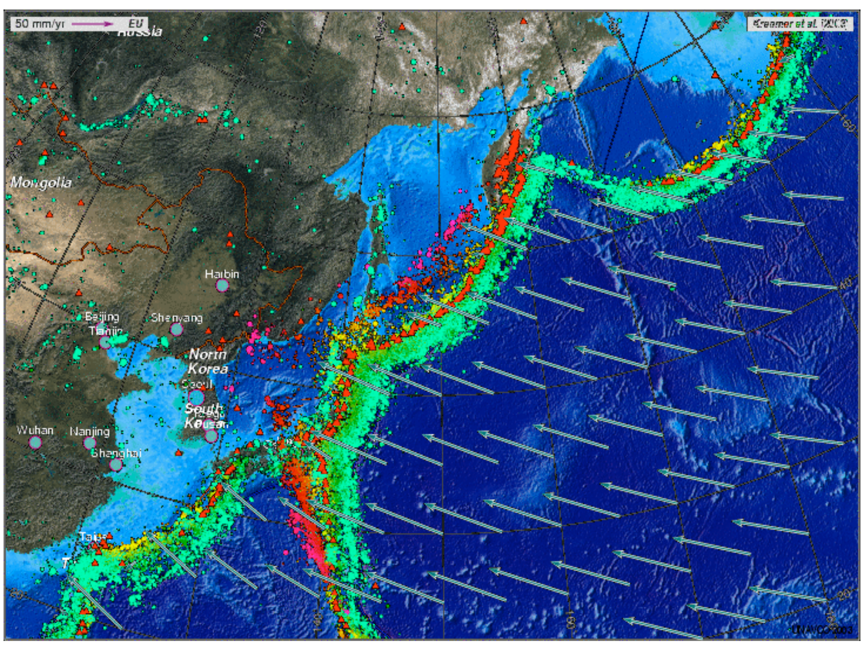


FIGURE A4. SEISMOTECTONIC SETTING OF THE KURIL-KAMCHATKA SEISMIC ZONE. BASEMAP AND SYMBOLS AS IN FIGURE A1. MODEL PLATE MOTIONS, SHOWN WITH RESPECT TO EURASIA, ARE FROM KREEMER ET AL. (2003).

The northwestern Pacific region (Figure A4) is among the most seismically active plate boundary zones in the world. Dominated by rapid convergence between the Pacific Plate and the North American and Eurasian plates, it results in a significant number of large, plate boundary earthquakes each year. The Kurile-Kamchatka Trench extends over 2000 km along the eastern margin of Russia, Kurile Islands, and the northernmost part of the Japanese island arc, from its intersection with the Aleutian Trench in the northeast to the Japan Trench in the southwest. Although the area is relatively sparsely populated, there are significant potential impacts on coastal communities. More importantly, the area is the site of a number of very large subduction megathrust earthquakes, whose impact has spread beyond the local source area. The plate boundary is associated with near-orthogonal convergence at rates from 75 to 85 mm/yr. The convergence is manifested most prominently by a chain of active volcanoes in the Kuril Islands and the Kamchatka Peninsula, consisting of some 162 active volcanoes. The plate boundary has been the site of 12 great (M>7.8) earthquakes and 90 large (M>7.0) earthquakes since 1900. The earthquake record includes one of the largest events in instrumental history, the M9.0 1952 Kamchatka earthquake, which ruptured a 500-km-long segment of the plate boundary, triggering a regional tsunami that resulted in 4000 deaths. Although most of these events produced limited damage in the sparsely populated area, the 1995 M7.0 earthquake in the Sakhalin Island produced nearly 2,000 casualties. Among the cities affected by the Kuril-Kamchatka seismic zone are Petropavlovsk and Yuzhnyi Sakhalinsk. The area is also affected by upper plate deformation resulting from relative motion between the Sea of Okhotsk 'microplate' and the Eurasian and North American plates. Coastal areas of Japan's northern island of Hokkaido may also be affected by earthquakes associated with the Kuril-Kamchatka zone. Coastal areas on the Pacific coast are at risk for local and regional tsunamis.

5. Japan and vicinity (Japan, Chinese Taipei): Plate A5

The horrific damage of the 2011 Tohoku (Japan) earthquake and tsunami focused the world's attention on the seismic hazard associated with plate convergence in and around Japan (Figure 20). The region's high seismic activity is associated with the interaction between three major plates: the Eurasian Plate, the Pacific Plate and the Philippine Sea plate, along with at least one proposed microplate, the Sea of Okhotsk block that adjoins the region to the north. In central Japan, a 'triple junction' marks the boundary between three convergent plate boundaries: the Pacific and Eurasian plates converge along the Japan Trench in the north; the Philippine Sea and Eurasian plates converge along the Nankai Trough in the southwest, and the Pacific and Philippine Sea plates converge along the Izu-Bonin Trench in the east. The Japan Trench extends approximately 800 km along the coast of Japan's northern islands of Honshu and Hokkaido, where it meets the Kuril-Kamchatka Trench in the north. The Nankai Trough and its south western extension, the Ryukyu (or Nansei-Shoto) Trench, extend 2000 km from central Japan, along the Ryukyu Islands, where it terminates in the arc-continent collision zone at the island of Taiwan. The Izu-Bonin (or Izu-Ogasawara) Trench, extends some 1200 km north-south from central Japan to join the Mariana Trench in the south. Convergence rates along these trenches vary considerably; the highest rates of convergence are observed along the Japan Trench, where they range from approximately 83 to 90 mm/yr; along the Nankai-Ryukyu system, they range from <40 to nearly 70 mm/year; and along the Izu-Bonin system, the rates vary from 45-56 mm/yr. The convergence is manifested in the active deformation and seismicity within the Japanese islands, and active volcanism associated with some 120 active volcanoes extending through the Japanese islands, the Ryukyu chain, and the Izu-Bonin islands.

The island of Taiwan is one of the most seismically active zones in the world. In that area, the Manila Trench subduction zone (discussed in the following section) gives way to an arc-continent collision, where the volcanic portion of the Luzon island arc—Taiwan's Coast Ranges—is in collision with the Asian continental margin. This collision manifests itself in the dramatic topographic relief of Taiwan, with the Central Range reaching elevations of >5000m, and zones of active faulting and seismicity throughout the island. Among the most actively deforming areas are the Longitudinal Valley fault system, which was the site of the M7.8 Hualien earthquake, and the Chelungpu Fault, the site of the 1999 M7.6 Chi-Chi earthquake. Smaller faults, such as the Shanchiao Fault near Taipei, pose particular threats to densely populated urban areas.

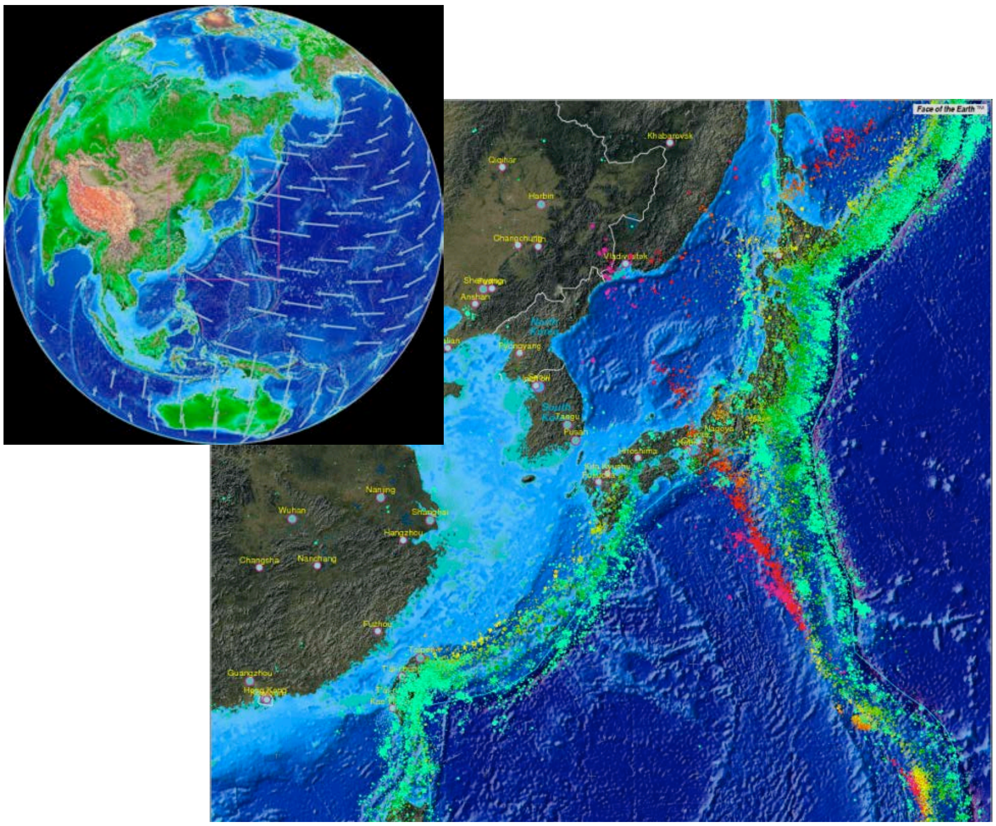


FIGURE A5. SEISMOTECTONIC SETTING OF JAPAN AND VICINITY. BASEMAP AND SYMBOLS AS IN FIGURE A1. INSET SHOWS MAP LOCATION WITH PLATE MOTIONS WITH RESPECT TO EURASIAN PLATE FROM KREEEMER ET AL. (2003).

The plate boundary has been the site of 15 great (M>7.8) earthquakes and nearly 200 large (M>7.0) earthquakes since 1900. The majority of these large events occurred along the Japanese segment of the plate boundary. Among the most destructive of these plate boundary earthquakes were the 1923 M7.9 Kanto (Tokyo) earthquake (99,000 casualties), the 2011 M9.0 Tohoku (Sendai) earthquake and tsunami (nearly 20,000 casualties), and the 1995 M7.1 Kobe earthquake (6,500 casualties). Among the major destructive earthquakes to strike Taiwan are the 1935 M7.1 earthquake (3500 casualties) and the 1999 M7.6 Chi-Chi earthquake (2,500 casualties). As demonstrated so graphically by the 2011 Tohoku event, secondary effects, particularly tsunamis, are an especially significant hazard to coastal communities. In addition to these plate boundary events, there is considerable seismic activity that takes place within the upper (Eurasian) plate on the Japanese Islands and within Taiwan. Shallow-depth, crustal earthquakes can cause considerable damage, as illustrated by the 1995 Kobe earthquake, which produced devastating economic damage (estimated at $100B or 2.5% of Japan's GDP). Coastal areas on the Pacific and Philippine Sea coasts are at risk for local and regional tsunamis.

6. Southeast Asia (Philippines, Taiwan, Indonesia): [Plate Not Yet Available]

The Southeast Asia region (Figure A6) represents one of the most complex and seismically active plate boundaries in the world. It involves interaction between four of the world's major plates—the Indian, Australian, Pacific, and Eurasian plates, as well as a number of minor plates—the Sunda, Philippine Sea, along with smaller blocks within the Indonesian and Philippine archipelagos. The area is densely populated, and produces significant potential impacts on populated areas of the Philippines, Indonesia, China, Vietnam, Malaysia, Singapore, and Chinese Taipei. The area is dominated by plate convergence, including subduction zones in the Philippines and Indonesia and collision zones in China, Taiwan, Mindoro and Mindanao (Philippines).

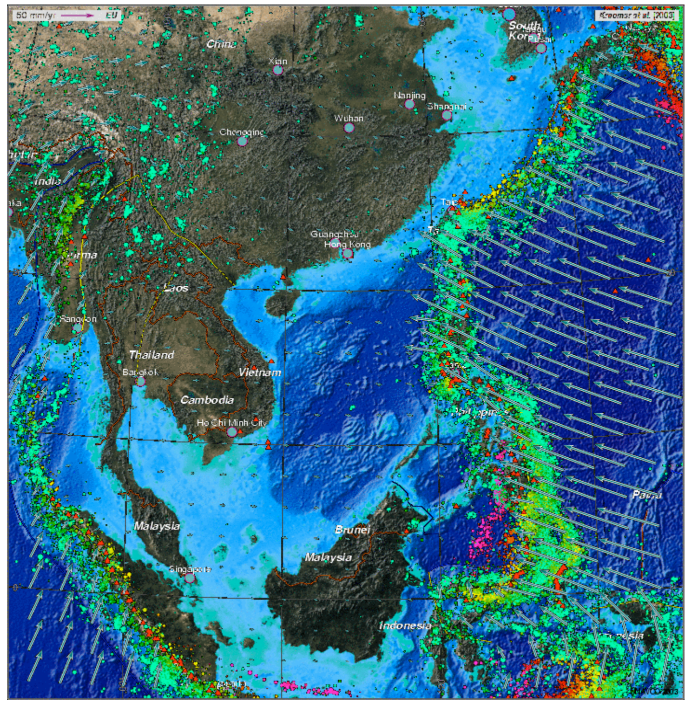


FIGURE A6. SEISMOTECTONIC SETTING OF SOUTHEAST ASIA. BASEMAP AND SYMBOLS AS IN FIGURE A1. MODEL PLATE MOTIONS, SHOWN WITH RESPECT TO EURASIA, ARE FROM KREEMER ET AL. (2003).

The Philippine archipelago (Figure A7) is part of a broad zone of convergence between the Sundaland block, (a fragment of the Eurasian plate) and the Philippine Sea plate. The tectonic setting of the Philippines is unusual in several respects: it is characterized by opposite-facing subduction systems on its east and west sides; the archipelago is cut by a major transcurrent fault, the Philippine Fault; and the arc complex itself is marked by active volcanism and high seismic activity. Subduction of the Philippine Sea Plate occurs along the eastern margin of the archipelago along the Philippine Trench and the East Luzon Trough. On the west side of Luzon, the South China Sea Basin subducts eastward along a series of deep-sea trenches, including the Manila Trench in the north, the Negros Trench in the central Philippines and the Sulu and Catobato trenches in the south. At its northern and southern terminations, subduction at the Manila Trench is interrupted by arc-continent collision, between the northern Philippine arc and the Eurasian continental margin at Taiwan and between the Sulu-Borneo Block and Luzon at the island of Mindoro. The Philippine fault, which extends for over 1200 km within the Philippine arc, is seismically active, with fault slip rates of about 9-35 mm/yr. The fault has been associated with major historical earthquakes, including the destructive 1990 M7.6 Luzon

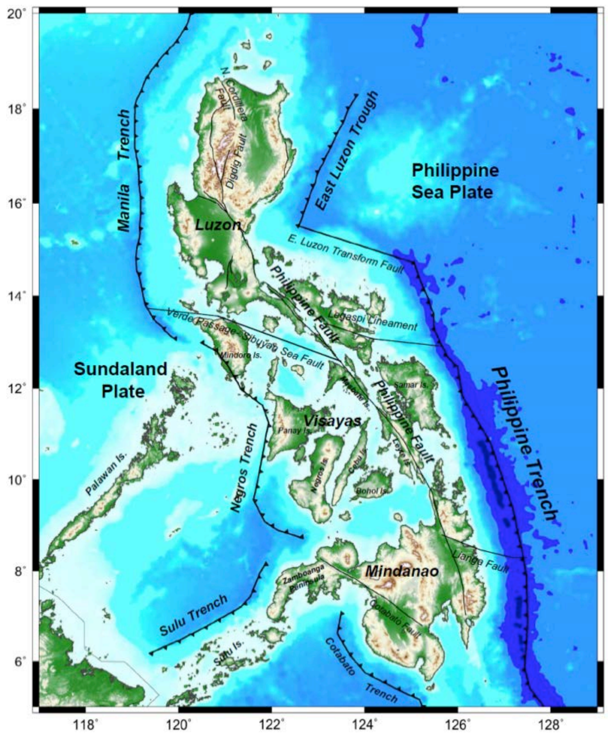


FIGURE A7. TECTONIC MAP OF THE PHILIPPINES, FROM GALGANA (2008).

earthquake. A number of other active intra-arc fault systems are associated with high seismic activity, including the Cotabato Fault and the Verde Passage – Sibuyan Sea Fault.

Fault slip rates along the Manila Trench range from ~20-70 mm/yr, increasing northward from the Mindoro collision zone; approaching Taiwan, these rates exceed 80 mm/yr. Further south, the convergence rate ranges from ~10-18 mm/yr along the Negros Trench to ~30-33 mm/yr along the Cotobato Trench. Along the eastern margin, subduction that along the Philippine Trench increases from south to north, from ~25 mm/yr to ~45 mm/yr. This rapid plate convergence results in active volcanism in the Philippines, including some 47 active volcanoes.

Seismic activity in the Philippines has included four great (M>7.8) earthquakes and 80 large (M>7) events. Among the most destructive events were the 1976 M7.6 Moro Gulf earthquake (7100 casualties), the 1968 M7.3 Casiguran earthquake (240 casualties), and the M7.8 1990 Luzon earthquake (2400 casualties). There have also been a number of tsunami-generating events in the Philippines, including the Moro Gulf earthquake noted above, whose tsunami resulted in more than 5000 deaths. Virtually the entire Philippine archipelago is at significant risk for earthquake damage, but the areas in closest proximity to plate boundaries and major intra-arc faults are at highest risk. Most low-lying coast communities are at risk for tsunami damage.

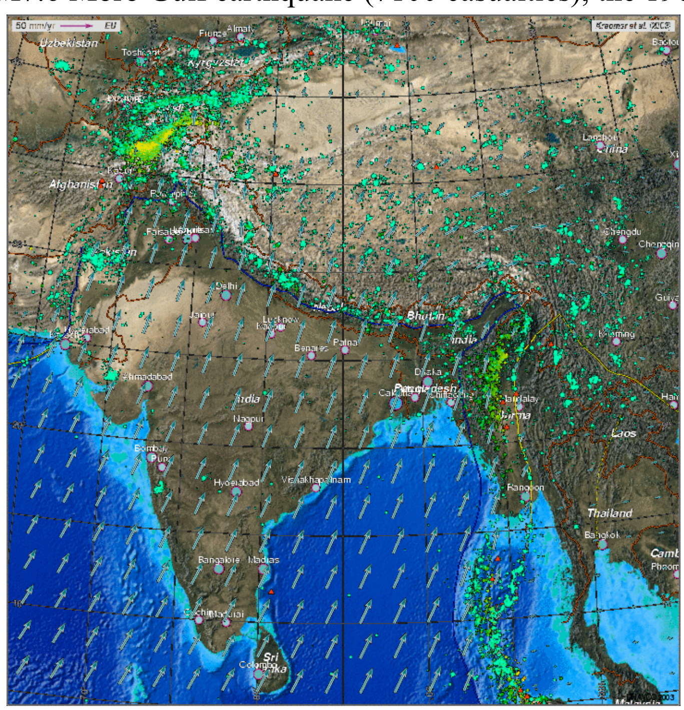


FIGURE A8. SEISMOTECTONIC MAP OF THE INDIA-EURASIA COLLISION ZONE. SYMBOLS AS IN FIGURE A1. PLATE MOTION VECTORS, PLOTTED WITH RESPECT TO EURASIA, ARE FROM KREEMER ET AL. (2003).

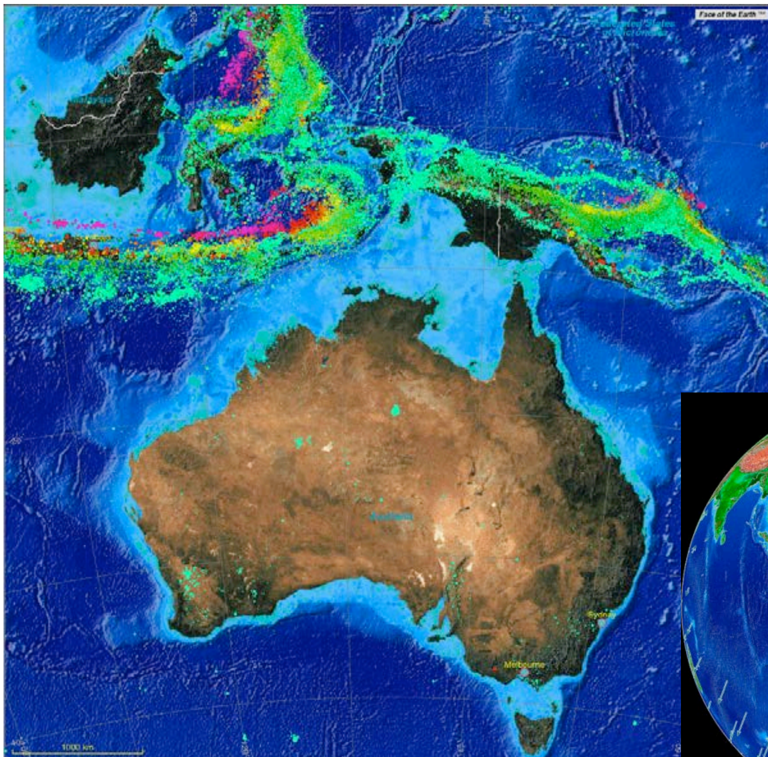
The neighboring areas of Taiwan and Indonesia are also subject to significant plate-boundary deformation and seismicity. They are discussed in the preceding and subsequent sections, respectively. Other countries in this region that are subject to significant earthquake hazard include China, Thailand, Malaysia, Singapore, and Vietnam. Of these, China (Figure A8) has by far the most serious seismic hazard, with a history of major, destructive earthquakes. China has been subject to five great (M>7.8) and over 50 large (M>7.0) earthquakes, with several notable events triggering major human disasters. These include the 1920 M8.3 Haiyuan earthquake (236,000 casualties), the 1976 M7.6 Tangshan earthquake (242,000 fatalities), and the 2008 M7.9 Wenchuan (Sichuan) earthquake (88,000 fatalities). Active deformation in China is largely a result of the ongoing convergence between the Indian and Eurasian plates. Because both plates are continental, this results in a continental collision zone, with active faulting, mountain-building, and seismic activity extending over 2000 km within the Eurasian continent. Major active faults, such as the Altyn Tagh Fault, the Kun Lun Fault, the Red River Fault, and the Xianshuihe Fault, have spatial extents on the order >1000 kilometers and the potential for major crustal earthquakes affecting millions of residents of China.

Much of Thailand, Vietnam, Malaysia, and Singapore are subject to significantly lower earthquake hazard than other economies in the APEC region. Because they are positioned within the more stable core of the Sundaland block, they are further removed from the major plate-boundary fault zones and measured deformation rates are considerably lower. Thus, the hazard associated with large, subduction-zone earthquakes and intraplate earthquakes is considerably lower than those economies situated directly astride a plate boundary zone. However, the risk of earthquakes remains significant in many areas. The mountainous area of northern Thailand, for instance, is associated with the India-Eurasia collision zone, and there is evidence of moderate levels of seismic activity and active faulting in this area. A number of active faults, albeit with relatively low rates of relative motion, have been documented in this area and provide a basis for regional seismic hazard assessment (Petersen et al., 2007)

7. Sunda arc (Indonesia, Australia, Papua New Guinea): Plate A6

The northern boundary of the Australian plate (Figure A9) is marked be plate convergence, high seismic activity and active volcanism. In this area the Australian plate converges with the Sunda plate (a detached fragment of Eurasia), the Pacific Plate, and the Bismarck Sea plate (a small 'microplate' north of New Guinea). It is characterized by exceptionally high seismicity at depths ranging from near-surface to 700 km depth.

The seismic zone has the potential to impact the economies of Indonesia, Papua New Guinea, Solomon Islands, and Australia. In the west, subduction of the oceanic portion of the Australian plate at the Java Trench gives way to arc-continent collision in the vicinity of the island of Timor, where the Australian continental shelf enters the subduction zone at the Timor Trough. Further east, this collision zone transitions to a complex plate boundary zone. Plate boundary deformation includes southward subduction of the Pacific plate at the New Guinea Trench back-arc extension in the Bismarck Sea, and northward subduction at the New Britain and South Solomon trenches. Plate convergence in this area gives rise to some 98 active volcanoes, including 48 in Papua New Guinea and 39 volcanoes in eastern Indonesia.



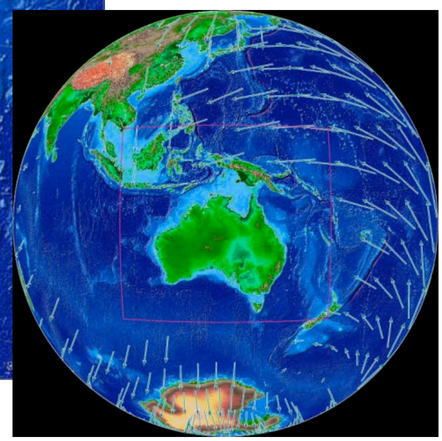


FIGURE A9. SEISMOTECTONIC SETTING OF THE SUNDA ARC AND AUSTRALIA. BASEMAP AND SYMBOLS AS IN FIGURE A1. INSET SHOWS LOCATION AREA WITH PLATE MOTION VECTORS PLOTTED WITH RESPECT TO THE EURASIAN PLATE, FROM KREEMER ET AL. (2003).

This highly active zone is site of some 25 great (M>7.8) and 340 large (M>7.0) earthquakes. Among the most destructive were earthquakes in eastern Indonesia in 1976 (6000 deaths), 1981 (1300 deaths), and 1992 (1700 deaths) and one in Papua New Guinea in 1998 (2700 deaths). The continent of Australia is subject to significant risk from intraplate earthquakes, including concentrations of activity in Western Australia, New South Wales, and Southern Australia. There have been a number of significant intraplate earthquakes, including the M6.9 1969 Meckaring earthquake and the 1988 Tennant Creek sequence (three earthquake with M6.3-6.7), which caused modest damage due to their remote location, and the moderate-sized (M5.6) 1989 Newcastle earthquake, which resulted in 13 deaths, 160 injuries, and estimated $4B in damage. Much of the region close to the plate boundary, including low-lying areas of Indonesia, Papua New Guinea, and the northern coast of Australia, is at risk of tsunami damage.

8. Western Indonesia arc (Indonesia, Singapore, Malaysia, Thailand): Plate A7

The world's attention was riveted to the impacts of plate boundary earthquakes in Indonesia following the devastating damage associated the 2004 Sumatra-Andaman earthquake and Indian Ocean tsunami. The earthquake proved to be one of the largest in recorded seismological history, and caused nearly 300,000 deaths in eight countries. The earthquake also focused attention on the potential for earthquakes in one region to have devastating impacts far outside its borders.

The region's high seismic activity (Figure A10) is largely a result of plate convergence between either the Indian Plate (in the north) or the Australian plate (in the south) and the Sunda plate, a detached fragment of the Eurasian Plate. The plate convergence rate varies from ~80 mm/yr of orthogonal plate convergence near Java to <60 mm/yr of highly oblique convergence in the Andaman Islands. This area of Indonesia is associated with 9 great (M>7.8) earthquakes and 60 large (M>7.0) earthquakes. Among the most destructive were the 2004 earthquake, a 2006 M6.4 earthquake near Java (5700 fatalities) and the M8.6 Sumatra "aftershock" of the 2004 earthquake (1300 fatalities). This segment of the Indonesian arc is characterized by very high volcanic activity, including 105 active volcanoes in a distinct chain extending through Sumatra, Java, and neighboring islands.

The region is also affected by significant hazard associated with upper plate crustal earthquakes, which can affect populated areas on Java, Sumatra, Bali, and other populated islands. Of particular concern is the Sumatra Fault, a 1900 km-long strike-slip fault with rates ranging from ~6 to > 30 mm/yr of lateral motion. Because the fault is highly segmented, it may limit the size of potential earthquakes to M<7.5. Nonetheless, the fault, along with other active faults within Java and Sumatra, has the potential for significant earthquake damage.

9. Southwest Pacific (New Zealand, Australia): Plate A8

The plate boundary between the Pacific and Australian plates in the southwest Pacific Ocean (Figure A11) is one of the most seismically active zones on Earth. It is characterized by exceptionally high seismicity at depths ranging from near surface to 700 km depth. Much of the area is sparsely populated, consisting of New Zealand and the oceanic island countries of Tonga, Fiji, Western Samoa, Vanuatu, and Solomon Islands. In New Zealand, the plate boundary is characterized by a complex transition from westward subduction of the Pacific plate beneath the New Zealand's North Island to transform faulting along the Alpine Fault in the South Island to eastward subduction of the Australian plate at the Puysegur Trench south of New Zealand. Northward from New Zealand, plate interaction is dominated by Pacific plate subduction at the Kermadec and Tonga Trenches, comprising a 2500 km-long subduction zone.

In northernmost Tonga, near the Samoa islands, the Pacific plate is torn, with its southern segment subducting beneath the Tonga Trench and its northern segment translating laterally at the Earth's surface along the Fiji Fracture Zone transform fault. To the west, the Australian plate subducts eastward at the New Hebrides Trench. Convergence rates range from <40mm/yr at the Hikurangi Trench in New Zealand to >80 mm/yr along the northern Tonga and New Hebrides trenches. The zone between Tonga and Vanuatu is characterized by sea-floor spreading in the back-arc region, and dominated by strike-slip and normal-faulting earthquakes.

The plate boundary zone is associated with some 69 active volcanoes extending through New Zealand, the Kermadec Islands, Tonga, Fiji, Samoa, and Vanuatu. The area is also the site of some 19 great (M>7.8) and 240 large (M>7) earthquakes. Nearly half of these earthquakes are at intermediate (70-300) or deep (>300) hypocentral depths, and thus have limited potential for serious damage.

There are also a significant hazards associated with plate boundary zone earthquakes that occur within the upper plate of the convergent zone. Such ‘intraplate’ earthquakes have included the M7.7 1931 Hawkes Bay (or Napier) earthquake, which resulted in approximately 250 casualties and the M6.3 2010 Christchurch earthquake, which caused nearly 100 fatalities.

Appendix B: List of Significant Earthquakes in the APEC Region

This appendix presents a tabular summary of the major earthquakes affecting each of the APEC economies. The tables below include both large-magnitude and destructive earthquakes since 1900. The source is the U.S. Geological Survey's PAGER (Prompt Assessment for Global Earthquake Response) catalogue (Allen et al., 2009). The full catalogue and additional background information are available at the PAGER cat website: http://earthquake.usgs.gov/research/data/pager/.

Australia:

Date	Magnitude	Latitude	Longitude	Depth	Total Deaths	Injuries
6/26/1924	8.3	-56.407	158.489	15		
3/16/1928	7.5	-22.281	170.476	35		
9/6/1943	7.6	-53	159	0		
10/5/1944	7.3	-22.5	172	120		
10/14/1968	6.8	-31.522	116.978	5	0	28
6/11/1970	7.3	-59.419	159.225	15		
6/2/1979	6.1	-30.818	117.105	6.2	0	1
7/6/1981	7.5	-22.25	171.814	30		
9/3/1987	7.4	-58.936	158.508	15		
5/23/1989	8	-52.507	160.596	1.7		
12/27/1989	5.4	-33.02	151.602	9.7	13	160
3/3/1990	7.6	-21.956	175.258	35.8		
1/4/1998	7.4	-22.247	171.014	100.4		

Canada:

Date	Magnitude	Latitude	Longitude	Depth	Total Deaths	Injuries
1/18/1901	7.1	60	-135	0		
11/6/1910	6.8	53	-135	0		
12/6/1918	6.8	50.662	-122.964	15		
5/26/1929	7	51.235	-130.556	15		
11/20/1933	7.1	72.996	-70.116	15		
6/23/1946	7.6	49.75	-124.5	0		
8/22/1949	8	53.75	-133.25	0		
6/24/1970	6.8	51.781	-130.941	20.3		
11/6/1997	5.1	46.771	-71.387	22.5	1	0

Chile:

Date	Magnitude	Latitude	Longitude	Depth	Total Deaths	Injuries
8/17/1906	8.5	-33	-72	0	1500	
11/11/1922	8.7	-28.553	-70.755	35	500	
12/1/1928	7.7	-35.086	-71.683	35	279	

Date	Magnitude	Latitude	Longitude	Depth	Total Deaths	Injuries
1/25/1939	7.7	-36.2	-72.2	0	28000	58500
4/6/1943	8.2	-30.75	-72	0	18	
12/17/1949	7.8	-54	-71	0	1	
12/17/1949	7.8	-54	-71	0	3	
5/21/1960	8.2	-37.825	-73.379	11.5		
5/22/1960	7.9	-38.146	-72.984	35		
5/22/1960	9.6	-38.294	-73.054	35	1000	3000
3/28/1965	7.4	-32.49	-71.21	71	337	350
7/9/1971	7.8	-32.558	-71.085	59	83	447
5/10/1975	7.8	-38.214	-73.001	29.5		
3/3/1985	7.9	-33.165	-71.872	31	200	2575
3/3/1985	7.9	-33.139	-71.761	35	177	2575
7/30/1995	8	-23.336	-70.265	40.5	3	59
6/13/2005	7.8	-20	-69.19	105.5	11	200

China:

Date	Magnitude	Latitude	Longitude	Depth	Total Deaths	Injuries
8/22/1902	7.7	40	77	0	5650	4350
8/30/1904	6.8	30	101	0	565	
12/22/1906	7.2	43.5	85	0	285	1100
12/21/1913	7.2	24.5	102	0	1314	1530
12/3/1915	7	29.5	91.5	0	170	
7/30/1917	7.3	29	104	0	1879	582
2/13/1918	7.2	23.54	117.243	15	2000	
12/16/1920	8.3	36.601	105.317	25	235502	36323
3/24/1923	7.2	30.553	101.258	25	450	
7/3/1924	7.1	36.632	83.903	35	255	
3/16/1925	7	25.688	100.494	25	5808	8303
5/22/1927	7.7	37.386	102.311	25	41419	
8/24/1930	5.5	30	100		200	
8/10/1931	7.9	46.571	89.965	35	10000	
3/6/1932	6	30.1	101.8		200	
12/25/1932	7.6	39.771	96.69	25	275	320
8/25/1933	7.3	31.81	103.541	25	6865	1925
9/20/1933	5	29.5	102.5		200	
5/16/1936	6.8	28.675	103.684	25	550	
8/1/1936	6	34.2	105.7		144	58
7/31/1937	6.9	35.252	115.153	25	3833	14266
4/6/1940	6	23.9	102.3		181	475

Date	Magnitude	Latitude	Longitude	Depth	Total Deaths	Injuries
5/5/1941	6	47	127.2		132	203
10/8/1941	6	31.7	102.3		139	
9/23/1945	6.3	39.5	119		600	200
5/25/1948	7.2	29.5	100.5	0	737	
6/27/1948	6.8	26.4	99.7		280	228
8/15/1950	8.6	28.5	96.5	0	3300	260
11/18/1951	7.7	30.5	91	0		
8/17/1952	7.7	30.5	91.5	0	54	157
9/23/1955	6.9	26.6	101.7	0	593	
2/5/1966	5.6	26.159	103.17	8.6	371	923
3/22/1966	5.6	37.549	114.994	14.9	8064	38451
1/4/1970	7.2	24.148	102.462	14.1	15621	26783
2/6/1973	7.7	31.361	100.503	5.9	2199	2743
5/10/1974	6.8	28.181	103.994	9.9	1541	1600
2/4/1975	7	40.665	122.646	15.8	1328	16980
7/27/1976	7.6	39.605	117.889	16.9	242419	164581
1/23/1981	6.5	30.942	101.105	4.8	126	724
11/6/1988	7	22.869	99.571	22.8	748	7751
4/26/1990	6.4	36.049	100.253	9.1	126	2049
2/3/1996	6.6	27.303	100.288	3.7	309	17057
11/14/2001	7.8	35.88	90.58	15		
2/24/2003	6.3	39.51	77.2	14	261	4000
5/12/2008	7.9	31.002	103.322	19	88287	374177

Indonesia:

Date	Magnitude	Latitude	Longitude	Depth	Total Deaths	Injuries
1/22/1905	7.8	1	123	90		
1/4/1907	7.5	2	94.5	50	400	
3/14/1913	7.9	4.5	126.5	0	138	
5/26/1914	7.9	-2	137	0	11	
1/21/1917	6.6	-7	116		1500	
6/28/1926	6.8	-0.051	101.522	35	222	
5/14/1932	8.1	0.258	126.169	35	5	20
12/28/1935	7.8	-0.345	98.147	35		
2/1/1938	8.4	-5.05	131.62	35		
12/21/1939	7.8	-0.208	122.565	35		
7/23/1943	7.6	-9.5	110	90	213	2096
11/4/1963	7.8	-6.735	129.685	35		
1/24/1965	8.2	-2.453	125.963	28.6	71	

Date	Magnitude	Latitude	Longitude	Depth	Total Deaths	Injuries
8/14/1968	7.3	0.064	119.69	17.3	200	58
6/11/1972	7.8	3.861	124.23	329.5		
6/25/1976	7.1	-4.524	140.104	2.8	6000	
7/14/1976	6.5	-8.228	114.773	25.7	563	2300
10/29/1976	6.8	-4.476	139.988	15	133	
8/19/1977	8.3	-11.125	118.38	20.9	189	75
1/19/1981	6.6	-4.515	139.283	20	1300	
8/1/1989	6.1	-4.479	138.984	10.6	120	125
12/12/1992	7.7	-8.495	121.833	33.1	1702	2144
2/15/1994	6.8	-5.007	104.251	19.8	207	2000
6/2/1994	7.8	-10.409	112.935	34.3	359	423
1/1/1996	7.9	0.707	119.902	25.2	10	63
2/17/1996	8.2	-0.919	136.975	35.9	166	423
6/17/1996	7.8	-7.146	122.512	590.9		
6/4/2000	7.9	-4.76	102.03	34.1	103	2585
12/26/2004	9	3.27	95.86	21.5	228000	
3/28/2005	8.6	2.05	97.06	33.7	1303	1146
5/26/2006	6.4	-7.96	110.34	19.7	5749	38568
7/17/2006	7.7	-9.32	107.33	24.3	665	9275
9/12/2007	8.5	-4.44	101.37	34	25	161
9/12/2007	7.9	-2.66	100.83	37.3		

Japan:

Date	Magnitude	Latitude	Longitude	Depth	Total Deaths	Injuries
6/15/1911	8.1	28	130	90	12	26
9/1/1923	7.9	35.405	139.084	35	99331	103733
5/23/1925	6.8	35.6	134.8	5	395	834
3/7/1927	7.1	35.802	134.924	9.6	2956	7806
11/25/1930	6.9	34.977	139.103	35	272	572
12/25/1930	7	35.1	133	5	272	
3/2/1933	8.4	39.224	144.622	35	3008	1092
11/5/1938	7.9	37.009	142.045	35	1	9
11/5/1938	7.8	37.108	142.081	35		
9/10/1943	7	35.25	134	0	1400	3259
12/7/1944	8.1	33.75	136	0	1223	2971
1/12/1945	6.8	34.75	136.75	0	2306	3866
12/20/1946	8.1	32.5	134.5	0	1362	3842
6/28/1948	7	36.5	136	0	5131	22203
3/4/1952	8.1	42.5	143	0	30	287

Date	Magnitude	Latitude	Longitude	Depth	Total Deaths	Injuries
11/25/1953	7.9	34	141.7	33	1	
3/20/1960	7.8	39.854	143.398	35		
5/16/1968	8.3	40.901	143.346	26	47	330
5/16/1968	7.8	41.595	142.788	11.3		
5/26/1983	7.7	40.473	139.092	15.1	104	163
7/12/1993	7.7	42.899	139.245	12	230	323
1/16/1995	6.9	34.578	135.015	15	6432	43792
9/25/2003	8.3	41.86	143.87	27	0	755

Mexico:

Date	Magnitude	Latitude	Longitude	Depth	Total Deaths	Injuries
9/23/1902	7.8	16	-93	0		
4/15/1907	7.9	17	-100	0	8	
6/7/1911	7.6	17.5	-102.5	0	1300	
11/19/1912	6.9	19	-100	80	164	
1/3/1920	7.8	19.26	-96.97		1500	
1/15/1931	7.8	16.053	-96.614	35	68	
6/3/1932	7.9	19.457	-104.146	25	400	400
6/18/1932	7.9	19.452	-103.632	54.3	52	
7/28/1957	7.8	16.886	-99.288	41.2	65	29
8/28/1973	7.2	18.233	-96.607	80.5	600	
11/29/1978	7.8	16.01	-96.602	24.4	9	100
9/19/1985	8	18.455	-102.368	20.2	9500	30000
10/9/1995	8	19.052	-104.208	25.6	58	100

New Zealand:

Date	Magnitude	Latitude	Longitude	Depth	Total Deaths	Injuries
11/15/1901	6.8	-43	173	0	1	
5/1/1917	8	-29	-177	0		
6/16/1929	7.5	-41.831	172.292	35	17	
2/2/1931	7.7	-39.772	176.025	35	256	
2/27/1955	7.8	-28.3	-175.5	0		
9/14/1959	7.8	-28.725	-177.075	35		
5/23/1968	7.2	-41.743	172.123	46.8	3	14
1/14/1976	7.8	-29.212	-177.635	42.2		
5/25/1981	7.6	-48.716	164.654	10.7		
10/20/1986	7.7	-28.157	-176.294	30		
3/2/1987	6.5	-38.051	176.873	50.3	1	25

Date	Magnitude	Latitude	Longitude	Depth	Total Deaths	Injuries
7/18/2004	5.4	-38.013	176.432	2.4	1	2
12/23/2004	8.1	-49.33	161.42	3.5	0	0
12/9/2007	7.8	-25.996	-177.514	152		
12/20/2007	6.6	-39.011	178.291	20	1	

Papua New Guinea:

Date	Magnitude	Latitude	Longitude	Depth	Total Deaths	Injuries
9/14/1906	8	-7	149	0		
9/20/1935	8.1	-3.92	141.33	35		
10/31/1970	7.3	-4.907	145.469	8.3	15	20
10/31/1970	7.3	-4.907	145.469	8.3	15	20
7/14/1971	8	-5.519	153.904	44.5	2	5
7/26/1971	8.1	-4.889	153.182	37		
7/20/1975	7.9	-6.612	155.095	61.1		
9/6/1988	4.3	-6.062	146.226	0	74	
10/13/1993	6.9	-5.848	146.136	21.3	60	200
10/13/1993	6.9	-5.848	146.136	21.3	60	200
7/17/1998	7	-2.975	142.692	10	2700	1000
11/16/2000	8	-3.99	152.26	27.6	2	
11/16/2000	7.8	-5.19	153.12	30		
11/17/2000	7.8	-5.49	151.88	29.7		
4/1/2002	5.3	-6.231	147.545	81.4	36	

Peru:

Date	Magnitude	Latitude	Longitude	Depth	Total Deaths	Injuries
12/12/1908	8.2	-14	-78	60		
8/6/1913	7.8	-17	-74	0		
11/4/1913	6.3	-14.2	-72.9	10	150	
5/24/1940	7.5	-11.119	-77.629	50.1	179	3500
8/24/1942	7.7	-14.975	-74.92	35	30	25
11/10/1946	6.8	-8.5	-77.5	0	1400	
11/1/1947	7.7	-10.5	-75	0	233	
5/21/1950	6	-13.5	-72		120	200
11/20/1960	7.8	-6.704	-80.62	35	66	2
8/15/1963	7.7	-13.717	-69.321	549.7		
10/17/1966	8.2	-10.799	-78.68	34.3	110	3000
10/1/1969	6.2	-11.835	-75.194	6	136	216
5/31/1970	7.5	-9.248	-78.842	73.2	70000	50000

Date	Magnitude	Latitude	Longitude	Depth	Total Deaths	Injuries
5/30/1990	6.5	-6.022	-77.197	17.2	135	800
11/12/1996	7.7	-14.96	-75.563	16.9	15	700
6/23/2001	8.4	-16.38	-73.5	32	139	2687
8/15/2007	8	-13.38	-76.61	39	514	1090

Philippines:

Date	Magnitude	Latitude	Longitude	Depth	Total Deaths	Injuries
8/15/1918	8.2	5.653	123.563	35	46	
11/11/1921	7.3	7.897	127.257	35	600	
4/14/1924	8.2	7.023	125.954	35		
5/25/1943	7.6	7.5	128	0		
1/24/1948	8.1	10.5	122	0	72	
3/19/1952	7.7	9.5	127.25	0		
3/31/1955	7.3	8.1	123.2	96	465	
8/1/1968	7.7	16.383	122.078	52.1	207	261
10/31/1975	7.6	12.537	125.999	51.1	1	
8/16/1976	8	6.292	124.091	58.5	7079	9928
7/16/1990	7.7	15.723	121.18	23.8	2430	3513
6/15/1991	5.6	15.165	120.316	46.4	137	

Russia:

Date	Magnitude	Latitude	Longitude	Depth	Total Deaths	Injuries
5/1/1915	7.9	47.5	154.5	35		
9/7/1918	7.6	46.812	150.253	242.4	23	7
2/3/1923	8.5	53.853	160.761	35	3	
11/4/1952	9	52.75	159.5	0		
5/4/1959	8	53.37	159.663	35	1	13
10/13/1963	8.6	44.763	149.801	26		
10/20/1963	7.9	44.764	150.567	27		
11/22/1969	7.8	57.729	163.595	9.2		
12/15/1971	7.8	56.023	163.173	21.8		
10/4/1994	8.3	43.832	147.332	33.3	12	382
5/27/1995	7	52.602	142.825	17.5	1995	750
12/5/1997	7.8	54.797	162.003	36.9		
9/27/2003	7.3	50.03	87.81	12.3	3	5
11/15/2006	8.3	46.58	153.27	10	0	1
1/13/2007	8.1	46.23	154.55	10		

Taiwan:

Date	Magnitude	Latitude	Longitude	Depth	Total Deaths	Injuries
11/5/1904	6.3	23.5	120.3		145	158
3/16/1906	6.8	23.6	120.4	5	1258	2385
11/21/1909	7.3	25.5	122	5	4	
6/5/1920	7.9	23.813	122.08	35	5	20
9/1/1922	7.5	24.506	122.04	35	5	7
4/20/1935	7.1	24.364	120.613	35	3276	12053
12/16/1941	7.1	23.251	120.391	35	357	718
10/21/1951	7.5	23.75	121.5	0	68	856
11/24/1951	7.3	23	122.5	0	17	91
2/13/1963	7.3	24.355	122.055	35	15	3
1/18/1964	6.4	23.149	120.655	20.3	106	650
1/25/1972	7.5	22.55	122.325	10	1	1
11/14/1986	7.3	23.976	121.723	25	15	45
9/20/1999	7.6	23.789	120.954	31.3	2489	11306

Thailand:

Date	Magnitude	Latitude	Longitude	Depth	Total Deaths	Injuries
4/22/1983	5.8	14.911	99.022	24.8		

Use of Scenario Earthquakes for Understanding Seismic Hazards in the APEC Region

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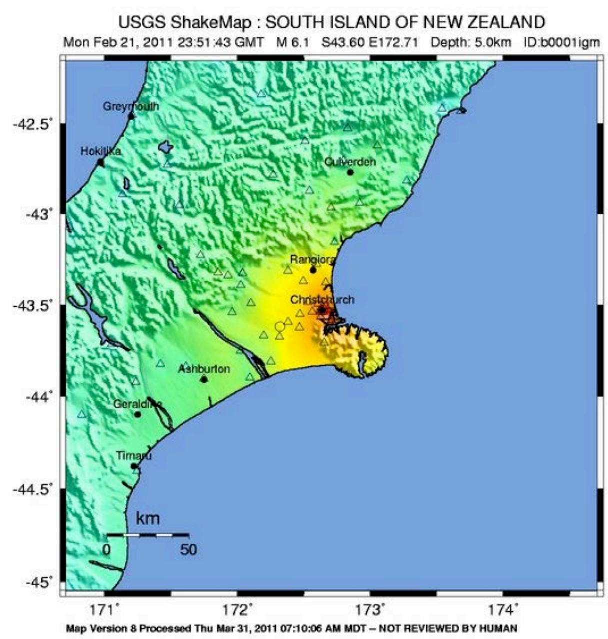
As an aid for understanding the potential impact of future earthquakes on the APEC (Asia-Pacific Economic Cooperation) economies, we have developed a series of scenario earthquakes, using resources developed by the U.S. Geological Survey National Earthquake Information Center (NEIC). These are hypothetical, future earthquakes whose characteristics are based on realistic estimates of potential magnitude and location that could affect populated areas in the APEC region. They are intended to provide a general sense of the potential scope of future seismically generated disasters that might impact the APEC economies, rather than to focus readers' attention on specific events. It is important to emphasize at the outset that these events are purely hypothetical. Their impacts are based on generalized estimates of earthquake-induced ground shaking; any actual earthquakes that strike these areas—even those with similar source characteristics—are likely to produce impacts that differ significantly from those projected here. Thus, these earthquake scenarios are purely for planning purposes, and are decidedly not intended to provide specific predictions of the actual impacts of specific future events.



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

FIGURE 1. EXAMPLE OF SHAKEMAP FOR THE 2011 CHRIST-CHURCH, NEW ZEALAND EARTHQUAKE (21 FEB 2011). THE MAP SHOWS ANTICIPATED LEVELS OF GROUND ACCELERATION OR SEISMIC INTENSITY THAT WOULD BE EXPECTED GIVEN THE EARTHQUAKE SOURCE LOCATION (STAR), MAGNITUDE, AND SOURCE MECHANISM.

The scenario events make use of a number of powerful new real-time data analysis systems developed by the USGS NEIC. The software is designed for rapid assessment of expected ground shaking associated with significant earthquakes around the globe. The two systems are the *ShakeMap* software (Wald et al., 2003; Allen et al., 2008), which provides rapid estimates of strong ground motion caused by major earthquakes, and the *Prompt Assessment of Global Earthquakes for Response* (PAGER) system (Wald et al., 2010), which provides rapid information about potential human and economic impacts of earthquakes.

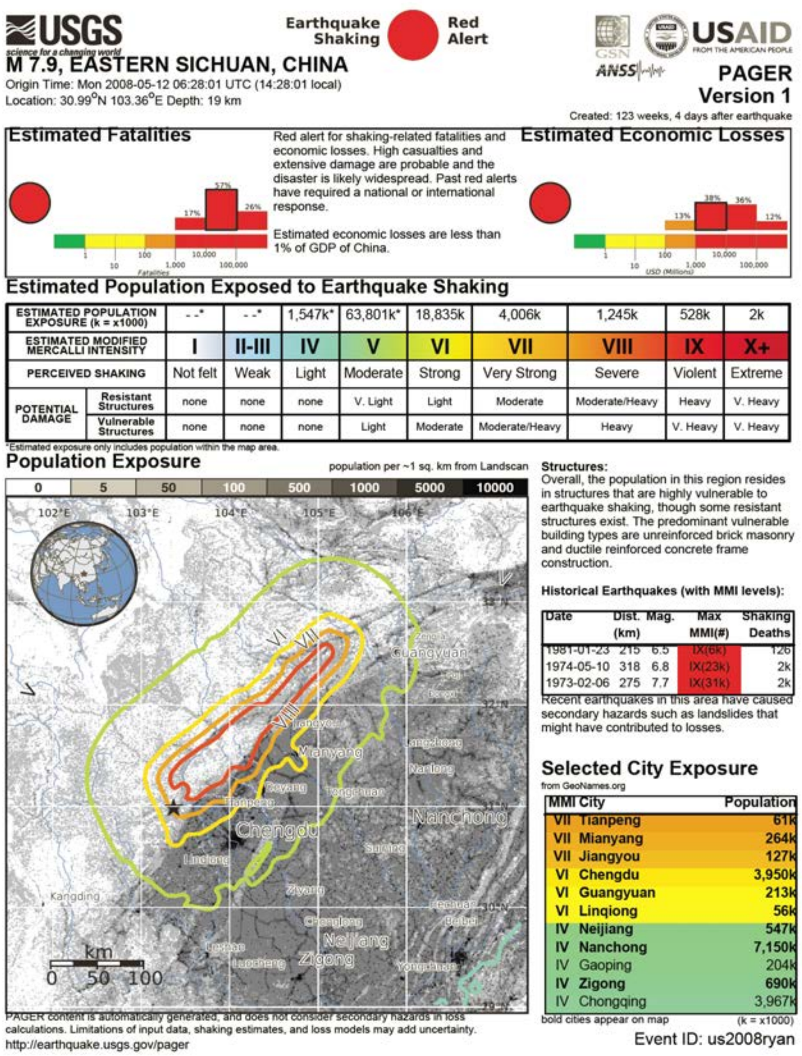


FIGURE 2. EXAMPLE OF PAGER OUTPUT FOR THE 2008 WENCHUAN (SICHUAN) CHINA EARTHQUAKE. THE MAP AT THE CENTER OF THE DISPLAY SHOWS THE EXPECTED GROUND MOTION (COLORED CONTOUR LINES) OVERLAIN ON A POPULATION DENSITY MAP (SHADED BACKGROUND), AS WELL AS TABLES ILLUSTRATING THE EXPECTED SEISMIC INTENSITY AT SELECTED POPULATION CENTERS AND PREVIOUS DESTRUCTIVE EARTHQUAKES IN THE AREA. THE PROBABILITY PLOTS (TOP) SHOW ESTIMATES OF PROBABLE FATALITIES (LEFT) AND ECONOMIC LOSSES (RIGHT), COLOR CODED BY SEVERITY.

The ShakeMap software, an example of which is illustrated in Figure 1, was developed to provide rapid assessment of strong ground shaking in the absence of direct measurement. The maps are designed to be used for emergency response, loss estimation, and public information. The software bases its forecasts on rapidly determined information about the earthquake source location, size, and rupture characteristics, combined with generalized constraints on wave propagation characteristics in the near-source area. The output of ShakeMap can be presented in the form of predicted ground motions in a number of frequency ranges, and in the form of an 'instrumental intensity', which uses a relatively simple, gradational ten-point scale to describe the estimated severity of ground shaking. An important characteristic of the ShakeMap software is that it can further constrain shaking estimates using information from nearby strong-motion seismographs, felt reports, or other indications of ground shaking amplitude. The shaking maps are continually updated as new information is received. One of the major innovations of ShakeMap (Wald and Allen, 2007) is the use of topographic information as a proxy for local site conditions and seismic wave amplification. This allows for the computation of anticipated spatial variability in shaking in areas for which local site geological information is lacking.

The PAGER system is designed to extend this rapid information one step further: to combine expected shaking information with population density and infrastructure vulnerability estimates to assess potential human and economic impact of significant earthquakes. The PAGER outputs (e.g., Figure 2) show estimated areas of strong shaking (from ShakeMap output) superimposed on a population density map (from the LandScan database) to derive an estimate of the number of residents exposed to a particular level of shaking. The impact is further refined by estimation of population and infrastructure vulnerability, based on the impact of past earthquakes. These vulnerability parameters vary considerably by country and location. Earle et al. (2009) demonstrated that these vulnerability parameters can vary by over three orders of magnitude from one region to another.

The potential for human and economic impact is summarized by a probabilistic estimate of the expected number of fatalities and direct economic losses. The results are presented on a logarithmic scale, emphasizing that the estimates are highly uncertain. Nonetheless, these estimates remain a highly useful characterization of the expected ranges of impact. They are summarized using a simple, four-level scale, color-coded using green, yellow, orange, and red circles to symbolize the degree of potential impact. For a given level of population exposure, less developed economies tend to suffer far greater human fatalities, whereas developed countries tend to suffer greater economic impact. Thus it is not uncommon to see one of these estimates in the 'yellow alert' zone, while the other is in the 'red alert' zone. A summary alert level is simply the higher of the two alert levels.

It is important to note that the PAGER system focuses only on direct shaking-related impacts, whereas much of the human and economic impact may derive from secondary effects of the ground shaking, notably liquefaction, landslides, fires, flooding, or tsunamis. These impacts are far more difficult to forecast without ancillary information, and thus are specifically excluded from the PAGER analysis.

As part of this study, we have prepared a series of scenario earthquakes, typically two for each APEC economy, illustrating the potential impact of hypothetical future significant earthquakes on each of these regions. The scenario earthquakes are based on reasonable projections of known tectonic processes, and the locations and potential fault area are based on known tectonic structures. The scenarios provide a rough comparison of the impacts of different types of future earthquakes in each region. In most cases, we have chosen two potential events: one, a very large (M8.0) subduction zone earthquake, typically occurring offshore, with potential impacts on populated areas near the coastline, and a second moderate-sized (M6.5) earthquake occurring within, or close to, a populated urban area. Examples of these two scenario events for the Philippines are shown in figures 3 and 4 (following pages).

It is perhaps surprising that in most of these cases, it is not the great subduction 'megathrust' earthquake that triggers the highest levels of predicted casualties and economic losses; rather it is the moderate-sized, but ill-placed urban earthquake that is estimated to produce the most devastating impacts. In many cases, like the Philippine scenario events, even a very large event located offshore of a major population center, produces significant, but not devastating impacts on the economy: several to tens of fatalities and several to tens of millions of dollars (US) of economic losses, far less than 1% of the Philippines' GDP. In contrast, a moderate-sized event whose epicenter and shallow depth places it close to an urban area has the potential to produce thousands to tens of thousands of fatalities and billions to tens of billions of dollars in economic losses—anywhere from 4 – 20% of the annual GDP of the economy.

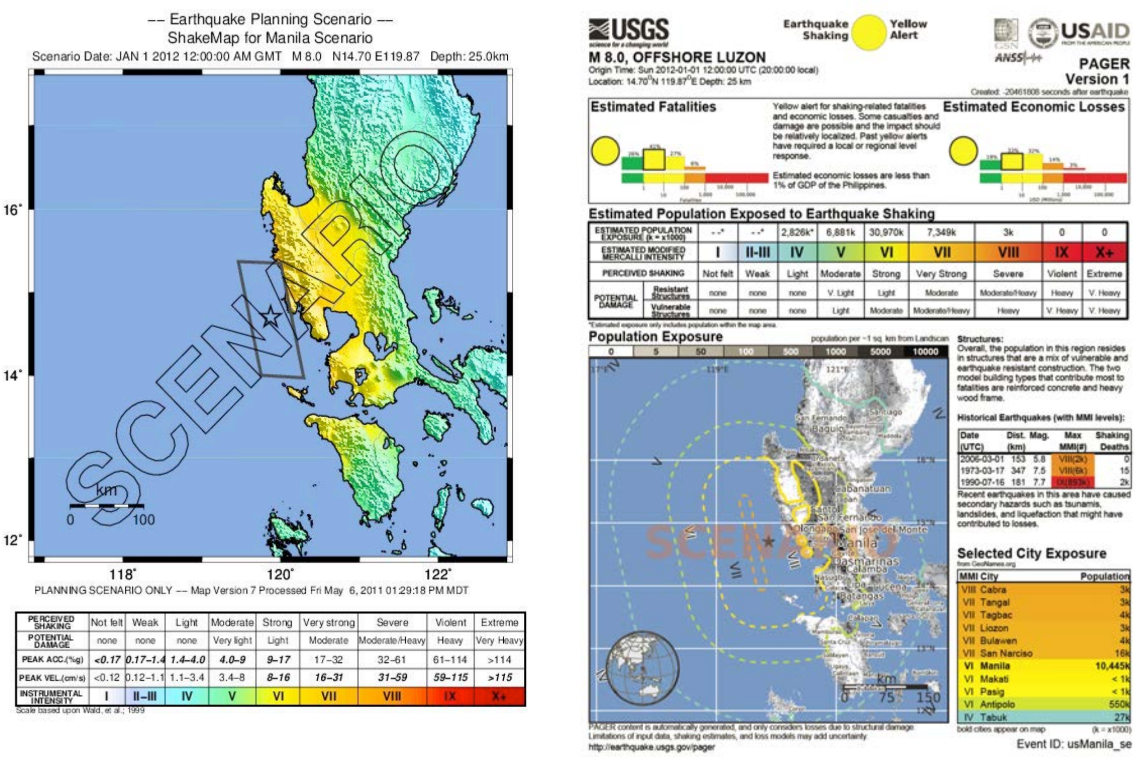


FIGURE 3. EXAMPLE OF A SCENARIO EARTHQUAKE FOR THE REPUBLIC OF THE PHILIPPINES, ILLUSTRATING THE EFFECTS OF A GREAT (M8.0) SUBDUCTION ZONE EARTHQUAKE OFFSHORE THE ISLAND OF LUZON. FIGURE AT LEFT SHOWS SHAKEMAP ESTIMATES OF GROUND MOTION SHAKING INTENSITY; FIGURE AT RIGHT SHOWS PAGER ESTIMATES OF EARTHQUAKE IMPACT FOR THIS SCENARIO.

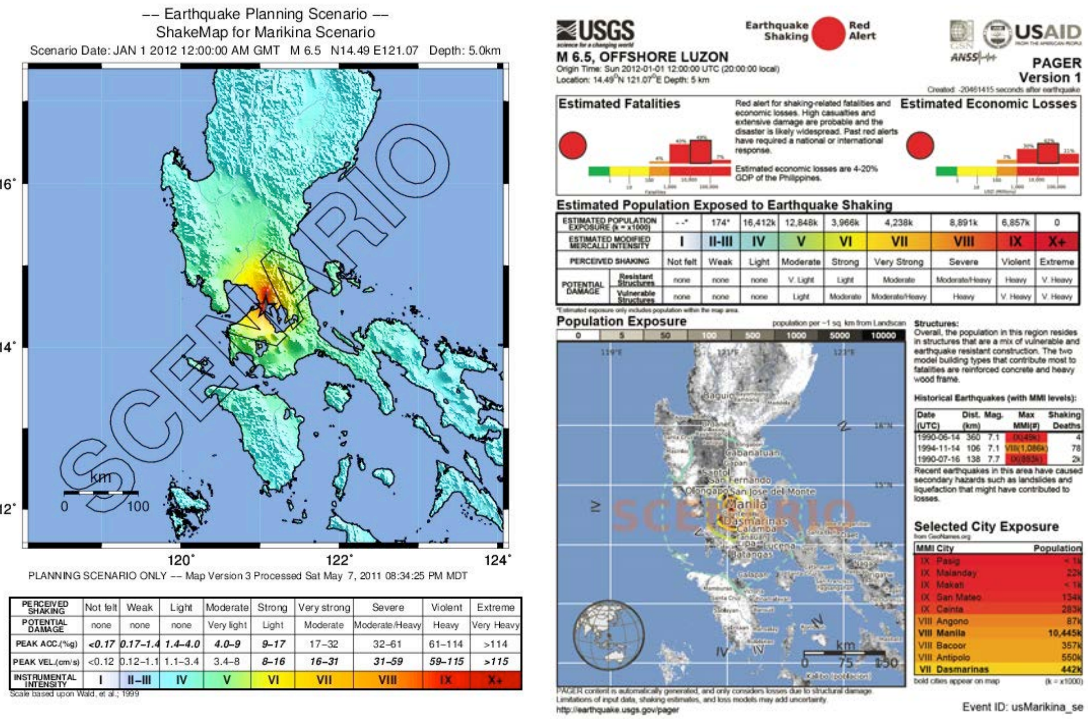


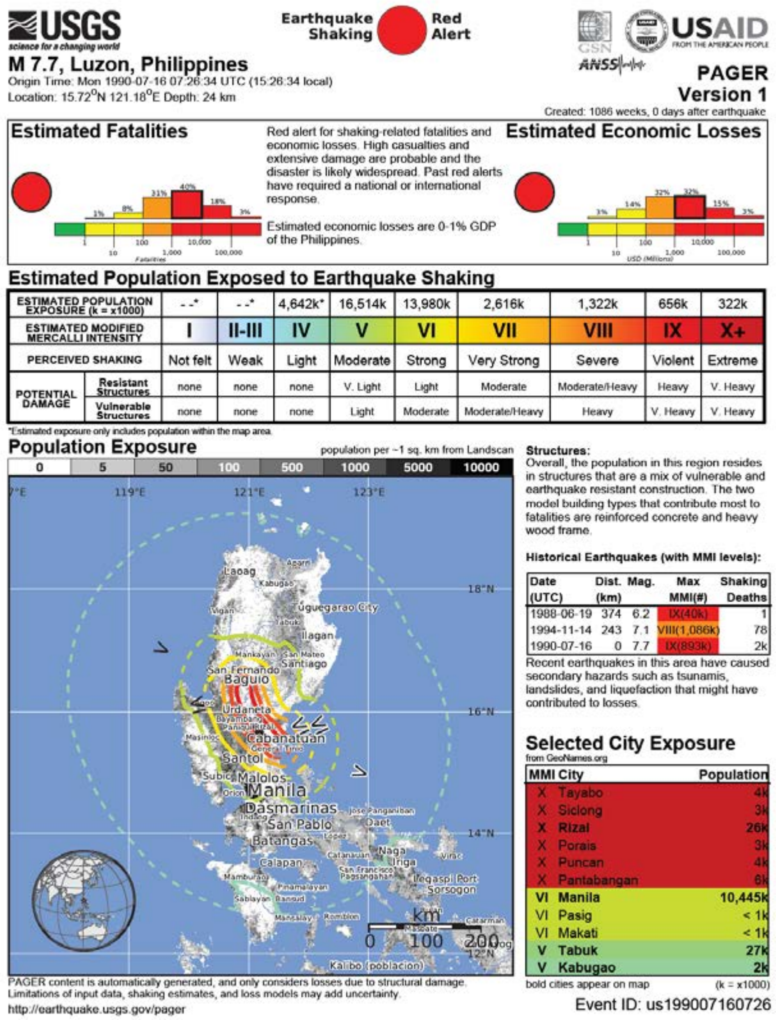
FIGURE 4. EXAMPLE OF A SCENARIO EARTHQUAKE FOR THE REPUBLIC OF THE PHILIPPINES, ILLUSTRATING THE EFFECTS OF A MODERATE (M6.5) CRUSTAL EARTHQUAKE NEAR THE DENSELY POPULATED AREA OF METRO MANILA. FIGURE AT LEFT SHOWS SHAKEMAP ESTIMATES OF GROUND MOTION SHAKING INTENSITY; FIGURE AT RIGHT SHOWS PAGER ESTIMATES OF EARTHQUAKE IMPACT FOR THIS SCENARIO.

The degree to which these scenario events can be considered realistic may be underscored by comparison with comparable earthquakes that have occurred in recent history. An example, showing the impact of the M7.7 1990 Luzon, Philippine earthquake, is presented in Figure 5 (following page). Actual losses were 1,621 deaths and an estimated $400M in impacts. These values are close to median estimates from PAGER. When examining these PAGER outputs for historical events, it is important to back-project population trends in order to compare the estimated and actual impacts for that event.

Scenario earthquakes for each of the APEC economies are presented in Appendix A. The pattern illustrated by figures 3 and 4 is repeated for many of the scenario events. That is, the large, plate boundary earthquakes occurring offshore tend to produce significant, but less than devastating impact on populated areas on land, whereas the smaller, crustal events produce major, localized damage in the epicentral area. Because these moderate (M5.5 – 6.5) earthquakes tend to produce damage in a relatively small area (generally several km to tens of km), the impact is strongly controlled by the exact location of the earthquake, with respect to large population centers. The 2011 Christchurch, New Zealand earthquake (M6.3) produced nearly 100 deaths and over $12B in insured losses. Its impact was far greater than that of the significantly larger M7.1 2010 Canterbury earthquake, largely because of its location, close to the urban center of a large New Zealand city (Hamburger and Mooney, 2011).
The reason for this major discrepancy between offshore (distant) and onshore (proximal) events relates to the patterns of seismic radiation and wave propagation illustrated by the

ShakeMap computations. The source-to-station distance associated with earthquakes occurring either offshore, at a significant distance from populated areas, or at depths of tens of km (or both), allows seismic waves to attenuate significantly before they strike a populated zone. In contrast, shallow crustal earthquakes tend to produce very strong ground shaking in a considerably smaller area capable of producing far more significant damage in the epicentral zone.

It is critical to reiterate that the PAGER forecasts specifically exclude secondary effects from the impact estimates. In the case of large, offshore events, it is these secondary effects, most notably tsunamis, which may trigger the vast majority of the fatalities and economic impact. This was the case for both the 2004 Indian Ocean tsunami and the 2011 Tohoku, Japan event, where the earthquake-related damage represented only a small fraction of the total damage produced by the tsunami and other secondary effects. In addition, PAGER's loss estimates are better tuned in some countries than in others. Countries with numerous damaging and fatal events over the past four decades provide data needed for more robust calibration; loss estimates for other countries, with few or no historic events, have more uncertainty.



ESTIMATED POPULATION EXPOSURE (k = x1000)	--*	--*	4,642k*	16,514k	13,980k	2,616k	1,322k	656k	322k
ESTIMATED MODIFIED MERCALLI INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+
PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
POTENTIAL DAMAGE: Resistant Structures	none	none	none	V. Light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy
POTENTIAL DAMAGE: Vulnerable Structures	none	none	none	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy	V. Heavy

Date (UTC)	Dist. (km)	Mag.	Max MMI(#)	Shaking Deaths
1988-06-19	374	6.2	IX(40k)	1
1994-11-14	243	7.1	VIII(1,086k)	78
1990-07-16	0	7.7	IX(893k)	2k

MMI	City	Population
X	Tayabo	4k
X	Siclong	3k
X	Rizal	26k
X	Porais	3k
X	Puncan	4k
X	Pantabangan	6k
VI	Manila	10,445k
VI	Pasig	< 1k
VI	Makati	< 1k
V	Tabuk	27k
V	Kabugao	2k

FIGURE 5. EXAMPLE OF PAGER OUTPUT FOR AN ACTUAL HISTORICAL EARTHQUAKE, THE M7.7 1990 LUZON, PHILIPPINES EARTHQUAKE.

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Appendix A: List of Scenario Earthquakes

This appendix consists of 24 scenario earthquakes, designed to illustrate the potential impact of earthquakes affecting the APEC economies. Where possible, we have chosen two scenario events affecting each of the economies, one illustrating the impact of a great subduction zone event affecting a neighboring APEC economy and the second, a moderate-sized (M6.5) crustal event located near a populated area. Each Scenario Event consists of a ShakeMap shaking intensity map (*Plate A*) and a PAGER damage estimate summary (*Plate B*).

Scenario 1: Chile – M8.0 Subduction event offshore Valparaiso

This event was designed to simulate a great (M8.0) subduction-zone thrust event, located on the subduction interface associated with the Peru-Chile Trench at 25 km depth, directly offshore Valparaiso and close to the capital, Santiago. Subduction zone strike and dip are estimated at 6º and 16º, respectively, from the Slab 1.0 model (Hayes and Wald, 2009; Hayes et al., 2012). This scenario demonstrates the potential for a widespread distribution of strong seismic shaking along the Chilean coast, with potential for significant casualties and economic damage affecting populated areas along the coast and inland as far as Santiago.

Scenario 2: Chile – M6.5 Strike-slip event near Antofagasta

This event was designed to simulate a moderate (M6.5) upper-plate event, located on a small, unnamed strike-slip fault south of Carmen Salar, near the city of Antofagasta. Fault zone strike and dip are estimated at 2º and 90º, respectively, from the Map of Quaternary Faults and Folds of Chile (Lavenu et al., 2003). This scenario demonstrates the potential for localized strong seismic shaking in the epicentral area, with potential for significant casualties and economic damage affecting a localized area near Antofagasta.

Scenario 3: Peru – M8.0 subduction event offshore Lima

This event was designed to simulate a great (M8.0) subduction-zone thrust event, located on the subduction interface associated with the Peru-Chile Trench at 25 km depth, directly offshore the capital, Lima. Subduction zone strike and dip are estimated at 332º and 25º, respectively, from the Slab 1.0 model (Hayes and Wald, 2009; Hayes et al., 2012). This scenario illustrates the broad swath of strong shaking predicted along the coast, with potential for significant casualties and economic damage affecting Lima and neighboring areas of the Peruvian coast.

Scenario 4: Peru – M6.5 strike-slip event near Lima

This event was designed to simulate a moderate (M6.5) upper-plate event, located at shallow depth (5 km) on a small unnamed strike-slip fault near the city of Lima. Fault zone strike and dip are estimated at 317º and 90º, respectively, from Macharé et al. (2009). This scenario demonstrates the potential for localized strong seismic shaking in the epicentral area, with potential for very severe casualties and economic damage affecting a localized area near Lima.

Scenario 5: Mexico – M6.5 normal-faulting event near Morelia

This event was designed to simulate a moderate (M6.5) upper-plate event, located at shallow depth (4.3 km) on the Morelia Fault, a normal fault near the city of Morelia. Fault zone strike and dip are estimated at 266º and 60º, respectively, from Garduño-Monroy et al. (2009). This scenario demonstrates the potential for localized strong *seismic shaking in the epicentral area, with potential for very severe casualties and economic damage affecting a localized area near Morelia.*

Scenario 6: Canada – M8.0 subduction event offshore Victoria, British Columbia

This event was designed to simulate a great (M8.0) subduction-zone thrust event, located on the Cascadia subduction interface at 25 km depth, directly offshore Victoria, B.C. and northwestern Washington State, USA. Subduction zone strike and dip are estimated at 314º and 14º, respectively, from McCrory et al. (2006). This scenario demonstrates the potential for strong shaking, and consequent economic losses, distributed over a broad swath of southwestern British Columbia and northeastern Washington.

Scenario 7: Russia – M8.0 subduction event offshore Petropavlovsk, Kamchatka

This event was designed to simulate a great (M8.0) subduction-zone thrust event, located on the subduction interface associated with the Kurile-Kamchatka Trench at 25 km depth, directly offshore Petropavlovsk, Kamchatka. Subduction zone strike and dip are estimated at 210º and 18º, respectively, from the Slab 1.0 model (Hayes and Wald, 2009; Hayes et al., 2012). This scenario demonstrates the potential for strong shaking along the coastal area of Kamchatka, with potential for moderate economic losses.

Scenario 8: Russia – M6.5 strike-slip event near Irkutsk

This event was designed to simulate a moderate (M6.5) crustal event, located on a small unnamed strike-slip fault near the city of Irkutsk at shallow depth (5 km). Fault zone strike and dip are estimated at 322º and 90º, respectively, from Sherman et al. (2009). This scenario demonstrates the potential for localized strong seismic shaking in the epicentral area, with potential for very severe casualties and economic damage affecting a localized area near Irkutsk.

Scenario 9: Japan – M8.0 subduction event along Nankai Trough

This event was designed to simulate a great (M8.0) subduction-zone thrust event, located on the Nankai Trough subduction interface at 25 km depth, directly offshore the island of Shikoku. Subduction zone strike and dip are estimated at 244º and 13º, respectively, from Park et al. (2002). This scenario demonstrates the potential for strong shaking throughout the island of Shikoku, and the potential for serious economic losses.

Scenario 10: Japan – M6.5 strike-slip event near Nagoya

This event was designed to simulate a moderate (M6.5) crustal event, located on the Tenpaku-kako strike-slip fault near the city of Nagoya at shallow depth (5 km). Fault zone strike and dip are estimated at 215º and 65º, respectively, from the Japanese Seismic Hazard Information Station (http://www.j-shis.bosai.go.jp/?lang=en). This scenario demonstrates the potential for localized strong seismic shaking in the epicentral area, with potential for very severe casualties and economic damage affecting a localized area near Nagoya.

Scenario 11: Taiwan – M8.0 subduction event near Ryukyu Trench

This event was designed to simulate a great (M8.0) subduction-zone thrust event, located on the Ryukyu subduction interface at 25 km depth, directly east of the Taiwan coast, and close to the city of Ilan. Subduction zone strike and dip are estimated at 259º and 15º, respectively, extrapolated from the Slab 1.0 model (Hayes and Wald, 2009; Hayes et al., 2012). This scenario illustrates the potential for significant shaking throughout northern Taiwan, but with potential for some casualties and significant economic impact.

Scenario 12: Taiwan – M6.5 normal fault event near Taipei

This event was designed to simulate a moderate (M6.5) crustal event, located on the Shanchiao normal fault near the city of Taipei at shallow depth (5 km). Fault zone strike and dip are estimated at 45º and 60º, respectively, from Cheng et al. (2009). This scenario demonstrates the potential for localized very strong seismic shaking in the epicentral area, with potential for very severe casualties and economic damage affecting a localized area near Taipei.

Scenario 13: Philippines – M8.0 subduction event offshore Manila

This event was designed to simulate a great (M8.0) subduction-zone thrust event, located on the Manila Trench subduction interface at 25 km depth, directly offshore Luzon and close to the capital, Manila. Subduction zone strike and dip are estimated at 350º and 30º, respectively, from local seismicity data (Bautista et al., 2001). This scenario demonstrates the potential for moderate shaking throughout western Luzon, with potential for casualties and significant economic damage.

Scenario 14: Philippines – M6.5 strike-slip event near Manila

This event was designed to simulate a moderate (M6.5) crustal event, located at shallow depth (5 km) on the Marikina strike-slip fault near the city of Manila. Fault zone strike and dip are estimated at 8º and 90º, respectively, from Nelson et al. (2000). This scenario demonstrates the potential for localized strong seismic shaking in the epicentral area, with potential for very severe casualties and economic damage affecting a localized area near Metro Manila.

Scenario 15: Indonesia – M8.0 subduction event offshore Bandung, Java

This event was designed to represent a great (M8.0) subduction-zone thrust event, located on the Java Trench subduction interface at 25 km depth, offshore the island of Java and close to the cities of Bandung and Jakarta. Subduction zone strike and dip are estimated at 299º and 14º, respectively, from the Slab 1.0 model (Hayes and Wald, 2009; Hayes et al., 2012). This scenario demonstrates the potential for moderate shaking in southwestern Java, with potential for moderate casualties and economic damage.

Scenario 16: Indonesia – M6.5 strike-slip event near Bandung, Java

This event was designed to simulate a moderate (M6.5) crustal event, located at shallow depth (5 km on the Cimandiria strike-slip fault near the city of Bandung. Fault zone strike and dip are estimated at 262º and 90º, respectively, from Dardji et al. (2009). This scenario demonstrates the potential for localized very strong seismic shaking in the epicentral area, with potential for very severe casualties and economic damage affecting a localized area near Bandung.

Scenario 17: Indonesia – M8.0 subduction event offshore Padang, Sumatra

This event was designed to represent a great (M8.0) subduction-zone thrust event, located on the Sunda subduction interface at 25 km depth, directly offshore Sumatra and close to the city of Padang. Subduction zone strike and dip are estimated at 315º and 15º, respectively, from the Slab 1.0 model (Hayes and Wald, 2009; Hayes et al., 2012). This scenario demonstrates the potential for moderate shaking near coastal areas of Sumatra and offshore islands, but relatively low probability of significant casualties and economic losses.

Scenario 18: Australia – M8.0 subduction event along Banda arc

This event was designed to represent a great (M8.0) subduction-zone thrust event, located on the Timor Trough subduction interface at 25 km depth, directly north of the northern Australia coast and about 450 km north of the city of Darwin. Subduction zone strike and dip are estimated at 253º and 20º, respectively, from Cardwell and Isacks (1978). Because of the earthquake's large distance from populated areas, this event has very low probability of producing significant damage.

Scenario 19: Australia – M6.5 strike-slip event near Perth

This event was designed to simulate a moderate (M6.5) crustal event, located at shallow depth (5 km) on the Darling strike-slip fault near the city of Perth. Fault zone strike and dip are estimated at 4º and 84º, respectively, from Clark (2010). This scenario demonstrates the potential for localized very strong seismic shaking in the epicentral area, with potential for significant casualties and very severe economic losses affecting a localized area near Perth.

Scenario 20: Thailand – M8.0 subduction event along Andaman Trench

This event was designed to represent a great (M8.0) subduction-zone thrust event, located on the Sunda subduction interface at 25 km depth, offshore Myanmar (Burma) and about 400 km west from the western border of Thailand. Subduction zone strike and dip are estimated at 298º and 19º, respectively, extrapolated from the Slab 1.0 model (Hayes and Wald, 2009; Hayes et al., 2012). Because of the earthquake's proximity to populated areas in western Myanmar, there is potential for significant casualties there; however, its large distance from populated areas in Thailand makes this event unlikely to produce significant damage within Thailand.

Scenario 21: Thailand – M6.5 strike-slip event near Chiang Mai

This event was designed to simulate a moderate (M6.5) crustal event, located at shallow depth (5 km) on the Mae Kuang strike-slip fault near the city of Chieng Mai. Fault zone strike and dip are estimated at 293º and 90º, respectively, from Rhodes et al. (2004). This scenario demonstrates the potential for localized very strong seismic shaking in the epicentral area, with potential for significant casualties and economic losses affecting a localized area near Chiang Mai.

Scenario 22: New Zealand – M8.0 subduction event along Hikurangi Trough

This event was designed to represent a great (M8.0) subduction-zone thrust event, located on the Hikurangi Trough subduction interface at 25 km depth, directly offshore the North Island's East Cape area, and close to the city of Gisborne. Subduction zone strike and dip are estimated at 200º and 30º, respectively, from the Slab 1.0 model (Hayes and Wald, 2009; Hayes et al., 2012). This scenario demonstrates the potential for significant shaking in coastal areas and the potential for casualties and significant economic losses.

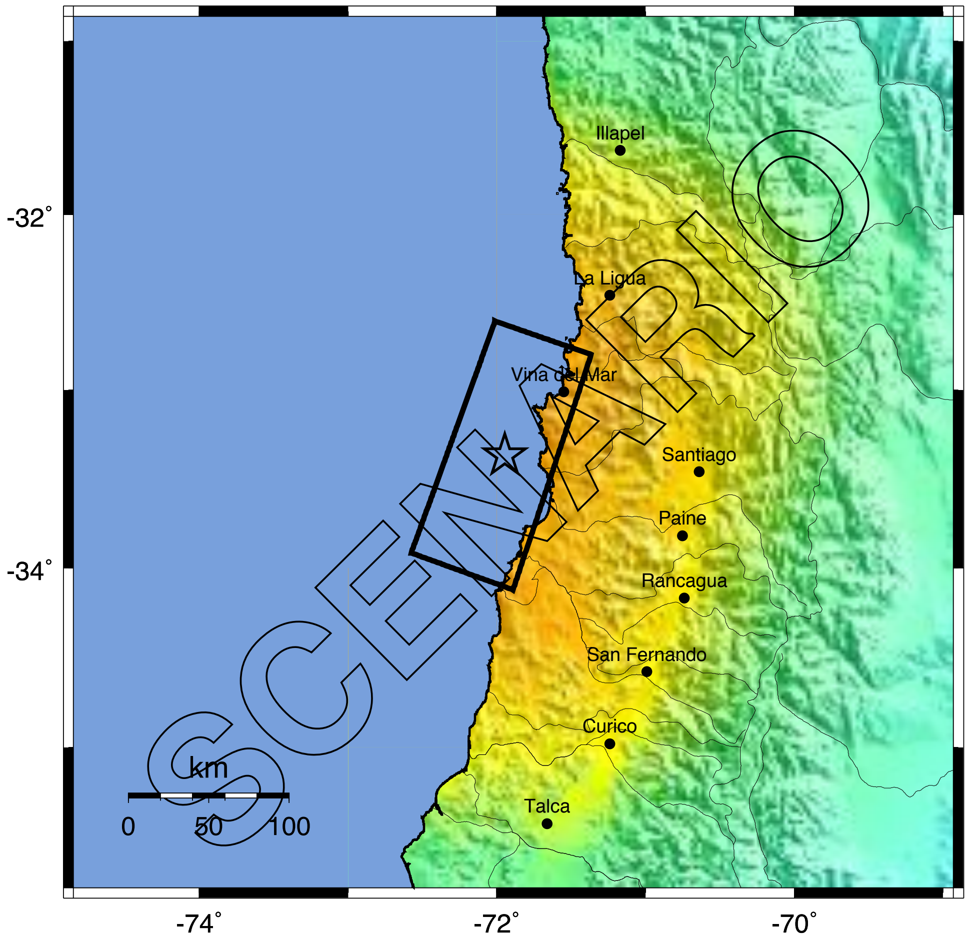
Scenario 23: New Zealand – M6.5 strike-slip event near Wellington

This event was designed to simulate a moderate (M6.5) crustal event, located at shallow depth (5 km) on the Wellington strike-slip fault near the city of Wellington. Fault zone strike and dip are estimated at 234º and 90º, respectively, from Van Dissen and Berryman (1996). This scenario demonstrates the potential for localized very strong seismic shaking in the epicentral area, with potential for significant casualties and severe economic losses affecting a localized area near Wellington.

Scenario 24: Papua New Guinea – M8.0 subduction event along New Britain trench

This event was designed to represent a great (M8.0) subduction-zone thrust event, located at 25 km depth on the subduction interface associated with the New Britain Trench, directly beneath New Guinea's Huon Peninsula and close to the city of Lae. Subduction zone strike and dip are estimated at 276º and 28º, respectively, from the Slab 1.0 model (Hayes and Wald, 2009; Hayes et al., 2012). This scenario demonstrates the potential for significant ground shaking in northeastern Papua New Guinea, with the potential for significant casualties and economic impact.

-- Earthquake Planning Scenario --
ShakeMap for Chile_Offshore Scenario
Scenario Date: Sun Jan 1, 2012 00:00:00 GMT M 8.0 S33.37 W71.95 Depth: 25.0km



PLANNING SCENARIO ONLY -- Map Version 1 Processed Wed Oct 5, 2011 12:12:37 PM MDT

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	***<.17***	***.17-1.4***	***1.4-3.9***	***3.9-9.2***	***9.2-18***	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	***8.1-16***	***16-31***	***31-60***	***60-116***	***>116***
INSTRUMENTAL INTENSITY	**I**	**II-III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X+**

USGS *science for a changing world*

Earthquake Shaking **Red Alert**

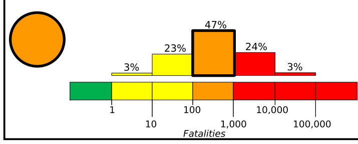
GSN ANSS **USAID** FROM THE AMERICAN PEOPLE

M 8.0, Offshore Santiago/Valparaiso

Origin Time: Sun 2012-01-01 00:00:00 UTC (21:00:00 local)
Location: 33.37°S 71.95°W Depth: 25 km
FOR TSUNAMI INFORMATION, SEE: tsunami.noaa.gov

PAGER Version 1
Created: 20 minutes after earthquake

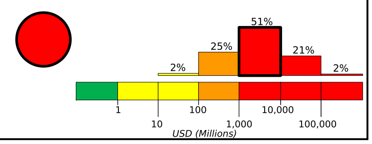
Estimated Fatalities



Red alert level for economic losses. Extensive damage is probable and the disaster is likely widespread. Estimated economic losses are 0-3% GDP of Chile. Past events with this alert level have required a national or international level response.

Orange alert level for shaking-related fatalities. Significant casualties are likely.

Estimated Economic Losses



Estimated Population Exposed to Earthquake Shaking

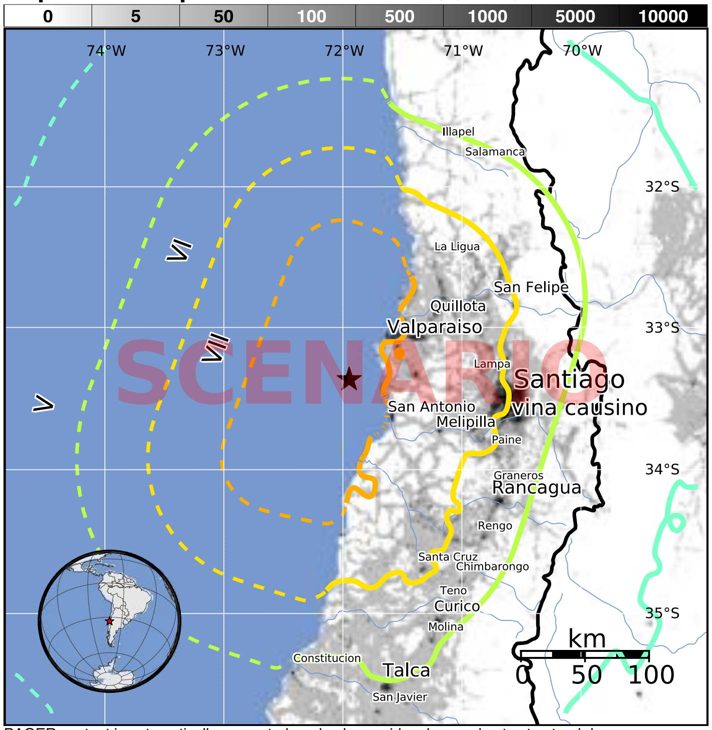
ESTIMATED POPULATION EXPOSURE (k = x1000)		- -*	- -*	27k*	418k*	3,489k	6,006k	579k	0	0
ESTIMATED MODIFIED MERCALLI INTENSITY		I	II-III	IV	V	VI	VII	VIII	IX	X+
PERCEIVED SHAKING		Not felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	Resistant Structures	none	none	none	V. Light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy
	Vulnerable Structures	none	none	none	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy	V. Heavy

*Estimated exposure only includes population within the map area.

Population Exposure

population per ~1 sq. km from Landscan

0	5	50	100	500	1000	5000	10000



PAGER content is automatically generated, and only considers losses due to structural damage. Limitations of input data, shaking estimates, and loss models may add uncertainty.

http://earthquake.usgs.gov/pager

Structures:
Overall, the population in this region resides in structures that are resistant to earthquake shaking, though some vulnerable structures exist. The two model building types that contribute most to fatalities are partially confined masonry and unreinforced masonry.

Historical Earthquakes (with MMI levels):

Date (UTC)	Dist. (km)	Mag.	Max MMI(#)	Shaking Deaths
1975-03-13	388	6.9	VIII(266k)	2
1997-10-15	285	7.1	VIII(3k)	7
1985-03-03	31	7.9	VII(5,433k)	177

Recent earthquakes in this area have caused secondary hazards such as tsunamis, landslides, and liquefaction that might have contributed to losses.

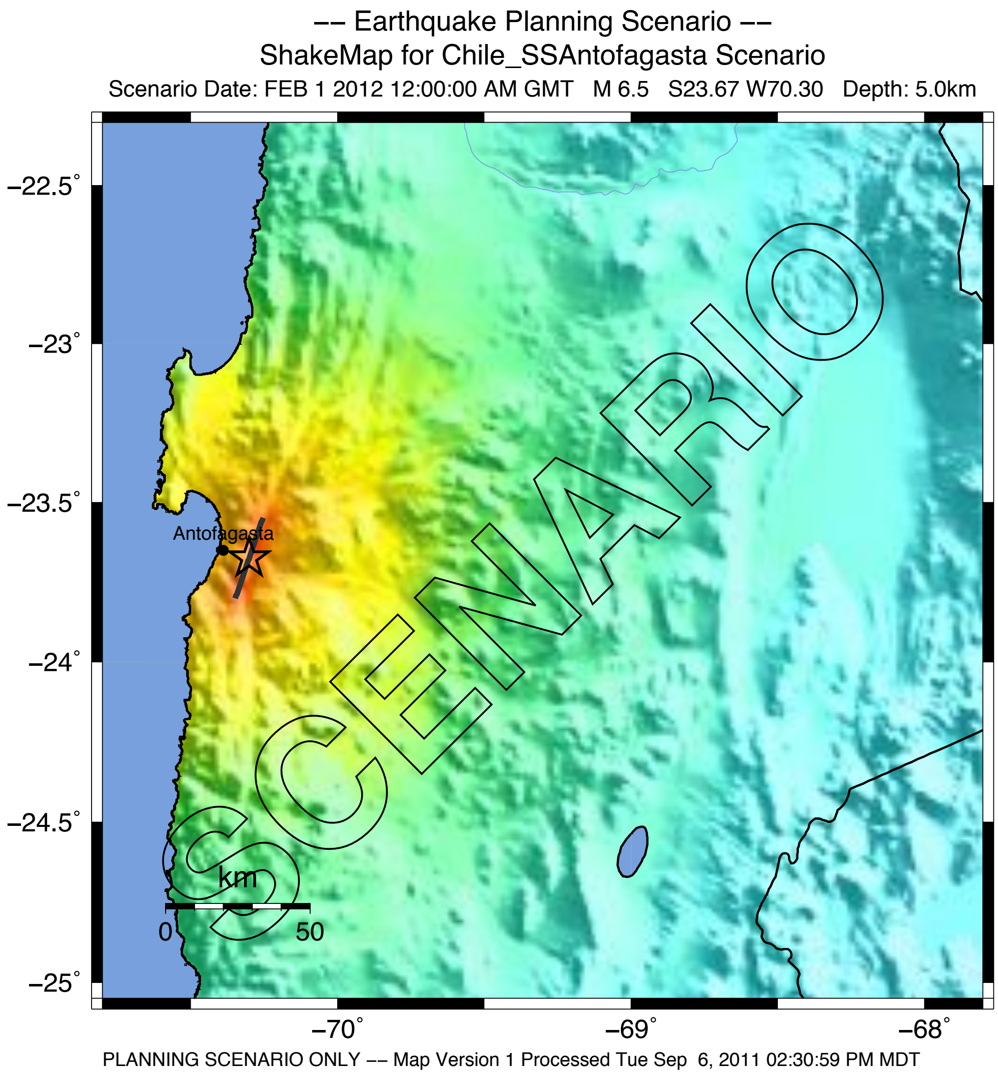
Selected City Exposure

from GeoNames.org

MMI	City	Population
VIII	**Valparaiso**	**282k**
VIII	Vina del Mar	295k
VIII	Hacienda La Calera	49k
VII	Llaillay	17k
VII	Quilpue	130k
VII	**San Antonio**	**86k**
VII	San Bernardo	250k
VII	**Santiago**	**4,837k**
VI	**vina causino**	**510k**
VI	**Rancagua**	**213k**
VI	**Talca**	**197k**

bold cities appear on map (k = x1000)

Event ID: usChile_Offshore_se



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<0.1	0.5	2.4	6.7	13	24	44	83	>156
PEAK VEL.(cm/s)	<0.07	0.4	1.9	5.8	11	22	43	83	>160
INSTRUMENTAL INTENSITY	I	II–III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Wald, et al.; 1999

USGS science for a changing world

Earthquake Shaking **Orange Alert**

USAID FROM THE AMERICAN PEOPLE

GSN ANSS

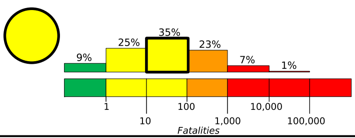
M 6.5, Strike Slip event inland of Antofagasta

Origin Time: Wed 2012-02-01 00:00:00 UTC (21:00:00 local)
Location: 23.67°S 70.30°W Depth: 5 km

PAGER Version 1

Created: 20 minutes after earthquake

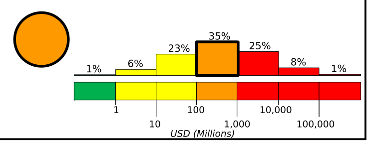
Estimated Fatalities



Orange alert level for economic losses. Significant damage is likely and the disaster is potentially widespread. Estimated economic losses are less than 1% of GDP of Chile. Past events with this alert level have required a regional or national level response.

Yellow alert level for shaking-related fatalities. Some casualties are possible.

Estimated Economic Losses



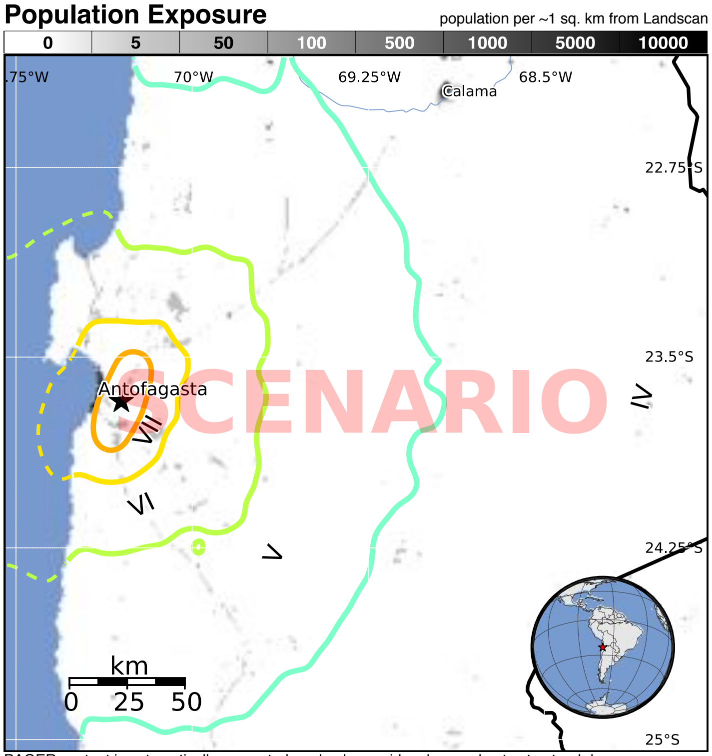
Estimated Population Exposed to Earthquake Shaking

ESTIMATED POPULATION EXPOSURE (k = x1000)		- -*	- -*	167k*	15k*	11k*	221k	87k	248	0
ESTIMATED MODIFIED MERCALLI INTENSITY		I	II-III	IV	V	VI	VII	VIII	IX	X+
PERCEIVED SHAKING		Not felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	Resistant Structures	none	none	none	V. Light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy
	Vulnerable Structures	none	none	none	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy	V. Heavy

*Estimated exposure only includes population within the map area.

Population Exposure

population per ~1 sq. km from Landscan



PAGER content is automatically generated, and only considers losses due to structural damage.
Limitations of input data, shaking estimates, and loss models may add uncertainty.

http://earthquake.usgs.gov/pager

Structures:
Overall, the population in this region resides in structures that are resistant to earthquake shaking, though some vulnerable structures exist. The two model building types that contribute most to fatalities are partially confined masonry and unreinforced masonry.

Historical Earthquakes (with MMI levels):

Date (UTC)	Dist. (km)	Mag.	Max MMI(#)	Shaking Deaths
1998-01-30	25	7.0	VIII(19k)	0
1983-10-04	319	7.6	VIII(504)	5
1981-06-21	378	5.7	VII(6k)	10

Recent earthquakes in this area have caused secondary hazards such as landslides that might have contributed to losses.

Selected City Exposure

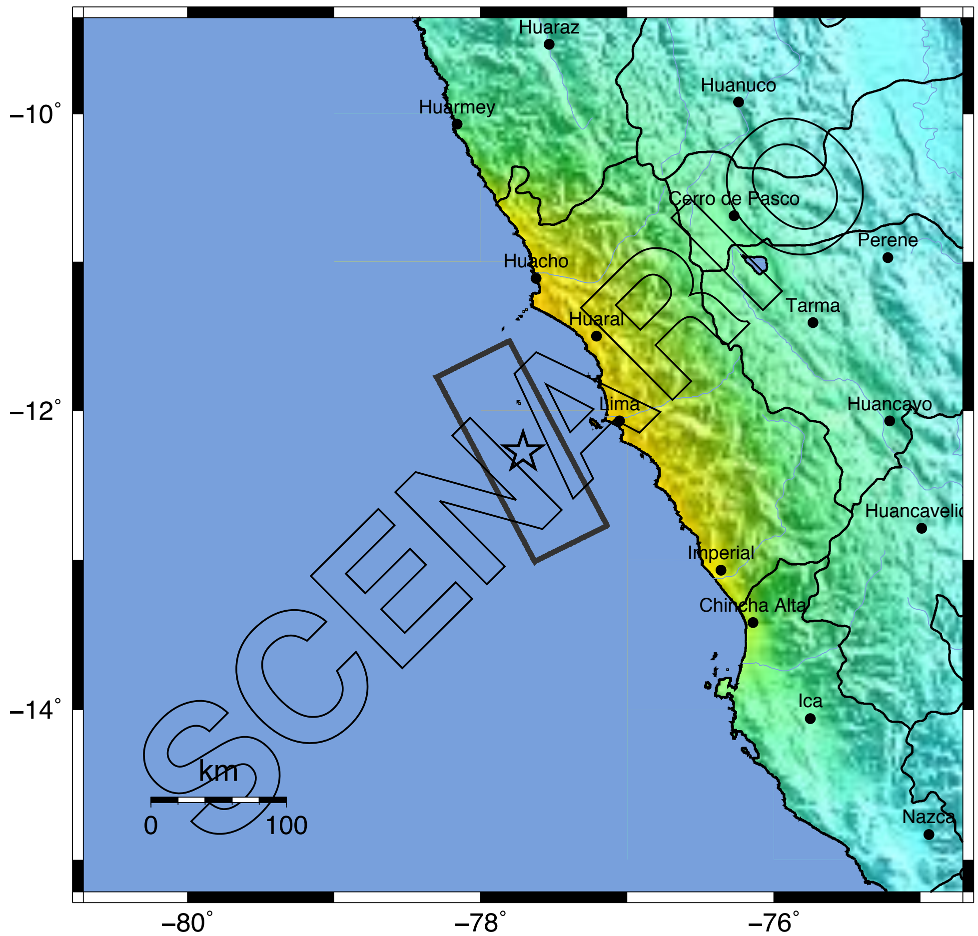
from GeoNames.org

MMI	City	Population
VIII	**Antofagasta**	**310k**
IV	**Calama**	**143k**
IV	San Pedro de A.	2k

bold cities appear on map (k = x1000)

Event ID: usChile_SSAntofagasta_se

-- Earthquake Planning Scenario --
ShakeMap for Peru_Subduction Scenario
Scenario Date: JAN 1 2012 12:00:00 AM GMT M 8.0 S12.28 W77.71 Depth: 25.0km



PLANNING SCENARIO ONLY -- Map Version 1 Processed Thu Sep 1, 2011 03:20:43 PM MDT

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<0.1	0.5	2.4	6.7	13	24	44	83	>156
PEAK VEL.(cm/s)	<0.07	0.4	1.9	5.8	11	22	43	83	>160
INSTRUMENTAL INTENSITY	I	II–III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Wald, et al.; 1999

Earthquake Shaking **Orange Alert**

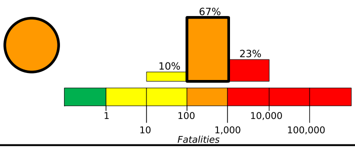
M 8.0, Subduction event Offshore Lima

Origin Time: Sun 2012-01-01 00:00:00 UTC (19:00:00 local)
Location: 12.28^{o}S 77.71^{o}W Depth: 25 km
FOR TSUNAMI INFORMATION, SEE: tsunami.noaa.gov

PAGER Version 1

Created: 20 minutes after earthquake

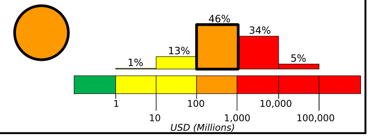
Estimated Fatalities



Orange alert for shaking-related fatalities and economic losses. Significant casualties and damage are likely and the disaster is potentially widespread. Past orange alerts have required a regional or national level response.

Estimated economic losses are 0-1% GDP of Peru.

Estimated Economic Losses



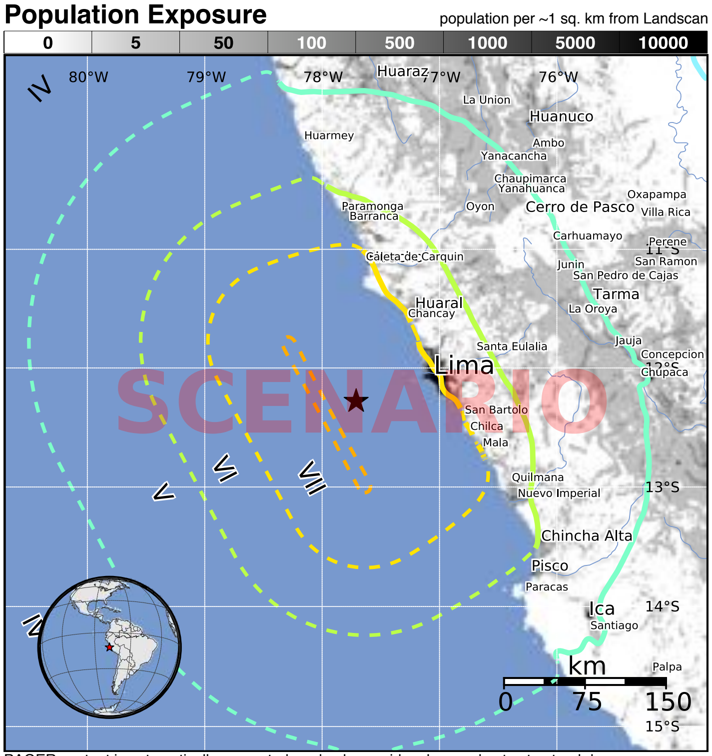
Estimated Population Exposed to Earthquake Shaking

ESTIMATED POPULATION EXPOSURE (k = x1000)		- -*	861*	1,852k*	1,859k	2,796k	7,215k	35	0	0
ESTIMATED MODIFIED MERCALLI INTENSITY		I	II-III	IV	V	VI	VII	VIII	IX	X+
PERCEIVED SHAKING		Not felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	Resistant Structures	none	none	none	V. Light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy
	Vulnerable Structures	none	none	none	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy	V. Heavy

*Estimated exposure only includes population within the map area.

Population Exposure

population per ~1 sq. km from Landscan



PAGER content is automatically generated, and only considers losses due to structural damage.
Limitations of input data, shaking estimates, and loss models may add uncertainty.
http://earthquake.usgs.gov/pager

Structures:
Overall, the population in this region resides in structures that are vulnerable to earthquake shaking, though some resistant structures exist. The two model building types that contribute most to fatalities are adobe/earthen and unreinforced masonry.

Historical Earthquakes (with MMI levels):

Date (UTC)	Dist. (km)	Mag.	Max MMI(#)	Shaking Deaths
2006-10-20	173	6.7	VII(405k)	0
1974-10-03	21	7.6	VIII(43k)	78
2007-08-15	171	8.0	VIII(493k)	514

Recent earthquakes in this area have caused secondary hazards such as tsunamis and landslides that might have contributed to losses.

Selected City Exposure

from GeoNames.org

MMI	City	Population
VII	Callao	813k
VII	**Lima**	**7,737k**
VII	**Huacho**	**55k**
VII	**Chilca**	**13k**
VII	**Caleta de Carquin**	**6k**
VII	**San Bartolo**	**6k**
V	**Ica**	**247k**
V	Huancayo	377k
V	**Cerro de Pasco**	**79k**
IV	**Huaraz**	**87k**
IV	**Huanuco**	**148k**

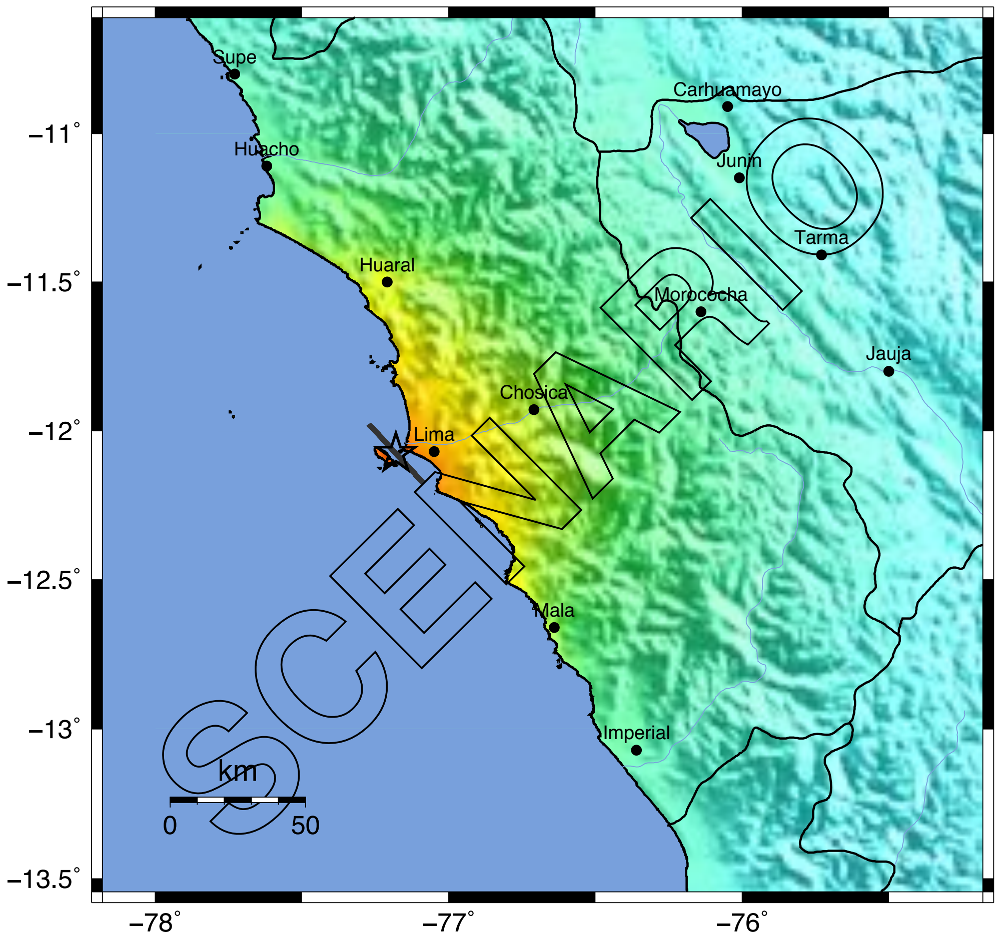
bold cities appear on map (k = x1000)

Event ID: usPeru_Subduction_se

–– Earthquake Planning Scenario ––

ShakeMap for Peru_SSLima Scenario

Scenario Date: FEB 1 2012 12:00:00 AM GMT   M 6.5   S12.08 W77.18   Depth: 5.0km



PLANNING SCENARIO ONLY –– Map Version 1 Processed Tue Sep 6, 2011 02:43:45 PM MDT

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	*<0.1*	*0.5*	*2.4*	*6.7*	*13*	24	44	83	>156
PEAK VEL.(cm/s)	<0.07	0.4	1.9	5.8	*11*	*22*	*43*	*83*	*>160*
INSTRUMENTAL INTENSITY	I	II–III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Wald, et al.; 1999

USGS
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Earthquake Shaking | Red Alert

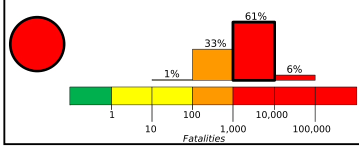
USAID FROM THE AMERICAN PEOPLE
GSN ANSS

M 6.5, Strike slip event Offshore Lima

Origin Time: Wed 2012-02-01 00:00:00 UTC (19:00:00 local)
Location: 12.08°S 77.18°W Depth: 5 km

PAGER
Version 1
Created: 20 minutes after earthquake

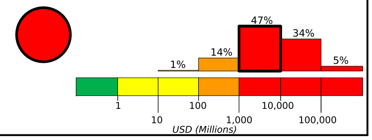
Estimated Fatalities



Red alert for shaking-related fatalities and economic losses. High casualties and extensive damage are probable and the disaster is likely widespread. Past red alerts have required a national or international response.

Estimated economic losses are 2-10% GDP of Peru.

Estimated Economic Losses



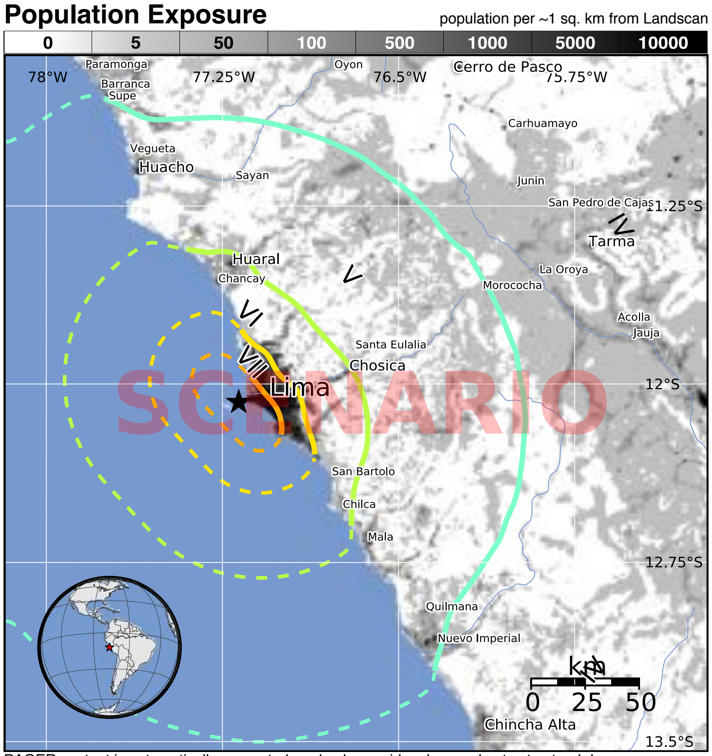
Estimated Population Exposed to Earthquake Shaking

ESTIMATED POPULATION EXPOSURE (k = x1000)		- -*	- -*	1,656k*	615k	606k	4,241k	4,357k	62k	0
ESTIMATED MODIFIED MERCALLI INTENSITY		I	II-III	IV	V	VI	VII	VIII	IX	X+
PERCEIVED SHAKING		Not felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	Resistant Structures	none	none	none	V. Light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy
	Vulnerable Structures	none	none	none	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy	V. Heavy

*Estimated exposure only includes population within the map area.

Population Exposure

population per ~1 sq. km from Landscan



PAGER content is automatically generated, and only considers losses due to structural damage.
Limitations of input data, shaking estimates, and loss models may add uncertainty.
http://earthquake.usgs.gov/pager

Structures:
Overall, the population in this region resides in structures that are vulnerable to earthquake shaking, though some resistant structures exist. The two model building types that contribute most to fatalities are adobe/earthen and unreinforced masonry.

Historical Earthquakes (with MMI levels):

Date (UTC)	Dist. (km)	Mag.	Max MMI(#)	Shaking Deaths
1982-11-19	319	6.6	IX(1k)	0
1974-10-03	42	7.6	VIII(43k)	78
2007-08-15	157	8.0	VIII(493k)	514

Recent earthquakes in this area have caused secondary hazards such as landslides that might have contributed to losses.

Selected City Exposure

from GeoNames.org

MMI	City	Population
IX	Callao	813k
VII	**Lima**	**7,737k**
VII	San Luis	9k
VII	Independencia	4k
VI	Santa Maria	15k
VI	**San Bartolo**	**6k**
VI	**Huaral**	**62k**
VI	**Chosica**	**89k**
IV	**Chincha Alta**	**153k**
IV	**Cerro de Pasco**	**79k**
IV	Huancayo	377k

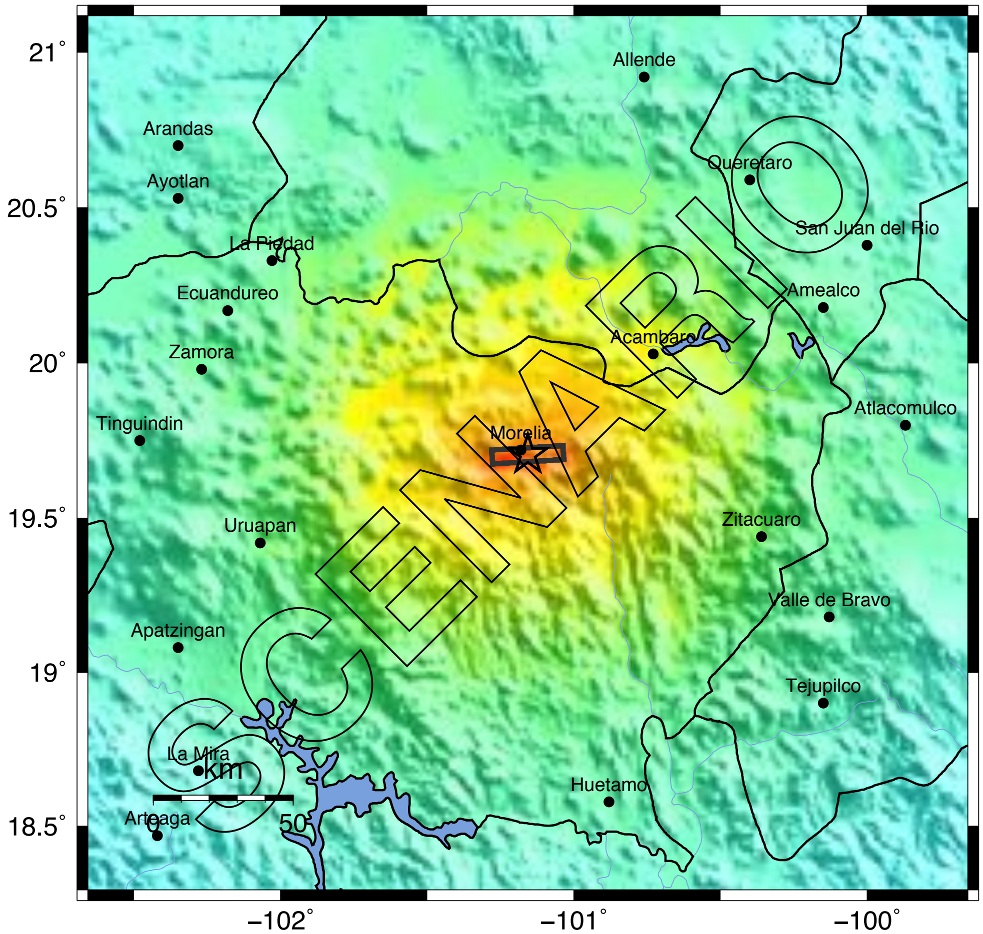
bold cities appear on map (k = x1000)

Event ID: usPeru_SSLima_se

–– Earthquake Planning Scenario ––

ShakeMap for Mexico_Morelia_Crustal Scenario

Scenario Date: FEB 1 2012 12:00:00 AM GMT M 6.5 N19.70 W101.16 Depth: 5.0km



PLANNING SCENARIO ONLY –– Map Version 1 Processed Tue Sep 6, 2011 01:51:57 PM MDT

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	*<0.1*	*0.5*	*2.4*	*6.7*	*13*	24	44	83	>156
PEAK VEL.(cm/s)	<0.07	0.4	1.9	5.8	*11*	*22*	*43*	*83*	*>160*
INSTRUMENTAL INTENSITY	I	II–III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Wald, et al.; 1999

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Earthquake Shaking **Red Alert**

GSN ANSS USAID FROM THE AMERICAN PEOPLE

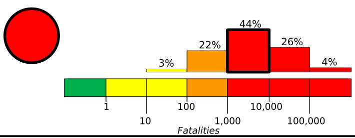
M 6.5, Crustal event under Morelia, Mexico

Origin Time: Wed 2012-02-01 00:00:00 UTC (17:00:00 local)
Location: 19.70°N 101.16°W Depth: 5 km

PAGER Version 1

Created: 20 minutes after earthquake

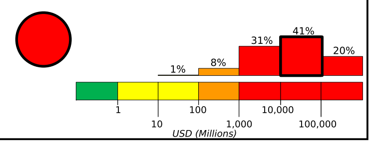
Estimated Fatalities



Red alert for shaking-related fatalities and economic losses. High casualties and extensive damage are probable and the disaster is likely widespread. Past red alerts have required a national or international response.

Estimated economic losses are 0-3% GDP of Mexico.

Estimated Economic Losses



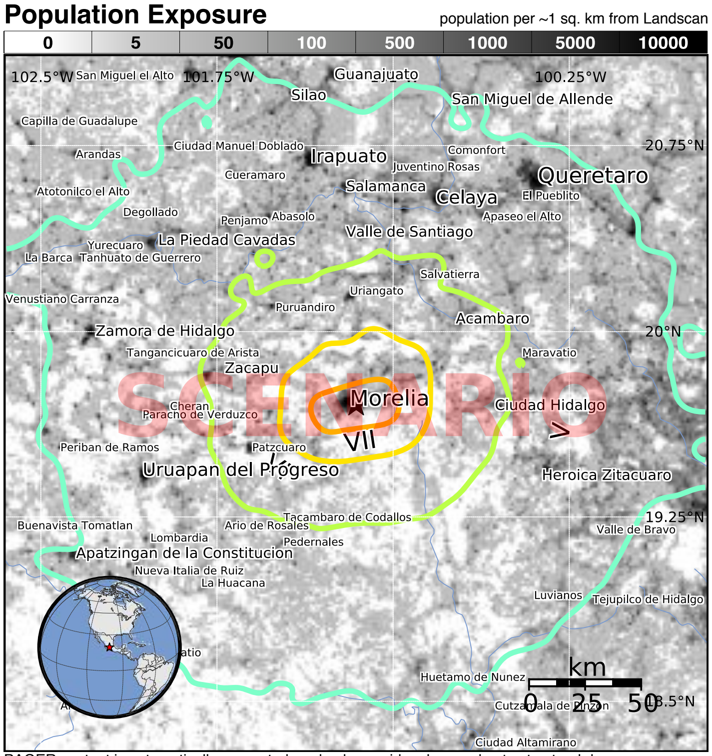
Estimated Population Exposed to Earthquake Shaking

ESTIMATED POPULATION EXPOSURE (k = x1000)		- -*	- -*	2,258k*	7,781k	1,331k	158k	484k	293k	0
ESTIMATED MODIFIED MERCALLI INTENSITY		I	II-III	IV	V	VI	VII	VIII	IX	X+
PERCEIVED SHAKING		Not felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	Resistant Structures	none	none	none	V. Light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy
	Vulnerable Structures	none	none	none	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy	V. Heavy

*Estimated exposure only includes population within the map area.

Population Exposure

population per ~1 sq. km from Landscan



PAGER content is automatically generated, and only considers losses due to structural damage.
Limitations of input data, shaking estimates, and loss models may add uncertainty.
http://earthquake.usgs.gov/pager

Structures:
Overall, the population in this region resides in structures that are a mix of vulnerable and earthquake resistant construction. The two model building types that contribute most to fatalities are adobe and nonductile reinforced concrete frame with masonry infill.

Historical Earthquakes (with MMI levels):

Date (UTC)	Dist. (km)	Mag.	Max MMI(#)	Shaking Deaths
1978-03-19	335	6.6	IX(214k)	1
1980-10-24	351	7.1	VIII(11k)	65
1985-09-19	188	8.0	VII(353k)	10k

Recent earthquakes in this area have caused secondary hazards such as landslides that might have contributed to losses.

Selected City Exposure

from GeoNames.org

MMI	City	Population
IX	**Morelia**	**593k**
VIII	Tarimbaro	5k
VIII	Charo	5k
VIII	Alvaro Obregon	8k
VII	Indaparapeo	7k
VII	Querendaro	9k
V	**Celaya**	**306k**
V	Uruapan del P.	237k
V	**Irapuato**	**340k**
V	**Queretaro**	**612k**
IV	Toluca	506k

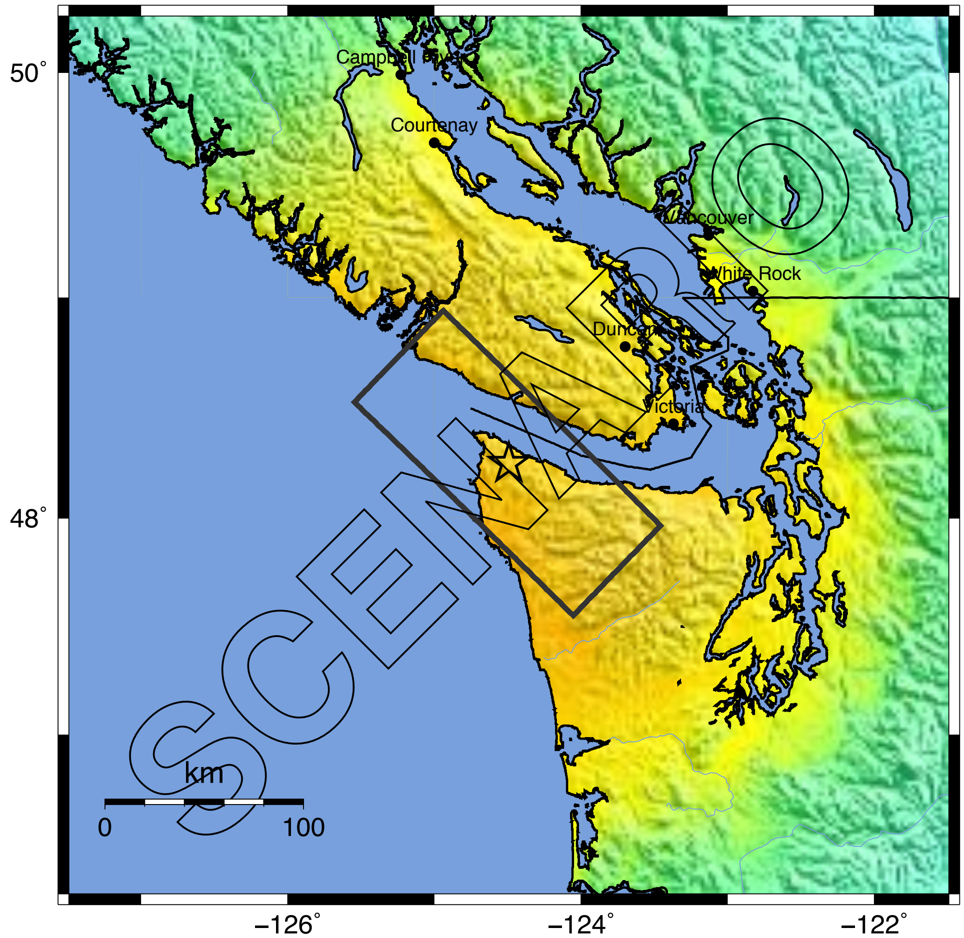
bold cities appear on map (k = x1000)

Event ID: usMexico_Morelia_Crustal_se

-- Earthquake Planning Scenario --

ShakeMap for Canada_Victoria_Subduction Scenario

Scenario Date: FEB 1 2012 12:00:00 AM GMT M 8.0 N48.25 W124.49 Depth: 25.0km



PLANNING SCENARIO ONLY -- Map Version 1 Processed Thu Sep 8, 2011 01:23:35 PM MDT

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<0.1	0.5	2.4	6.7	13	24	44	83	>156
PEAK VEL.(cm/s)	<0.07	0.4	1.9	5.8	11	22	43	83	>160
INSTRUMENTAL INTENSITY	I	II–III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Wald, et al.; 1999

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Earthquake Shaking **Red Alert**

GSN ANSS USAID FROM THE AMERICAN PEOPLE

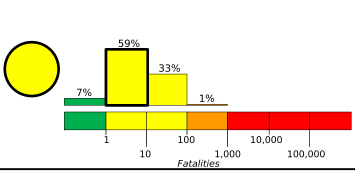
M 8.0, Subduction event offshore Victoria, Canada

PAGER Version 1

Origin Time: Wed 2012-02-01 00:00:00 UTC (17:00:00 local)
Location: 48.25°N 124.49°W Depth: 25 km
FOR TSUNAMI INFORMATION, SEE: tsunami.noaa.gov

Created: 20 minutes after earthquake

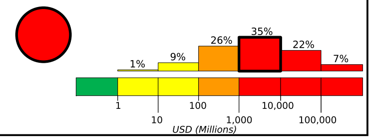
Estimated Fatalities



Red alert level for economic losses. Extensive damage is probable and the disaster is likely widespread. Estimated economic losses are less than 1% of GDP of the United States. Past events with this alert level have required a national or international level response.

Yellow alert level for shaking-related fatalities. Some casualties are possible.

Estimated Economic Losses



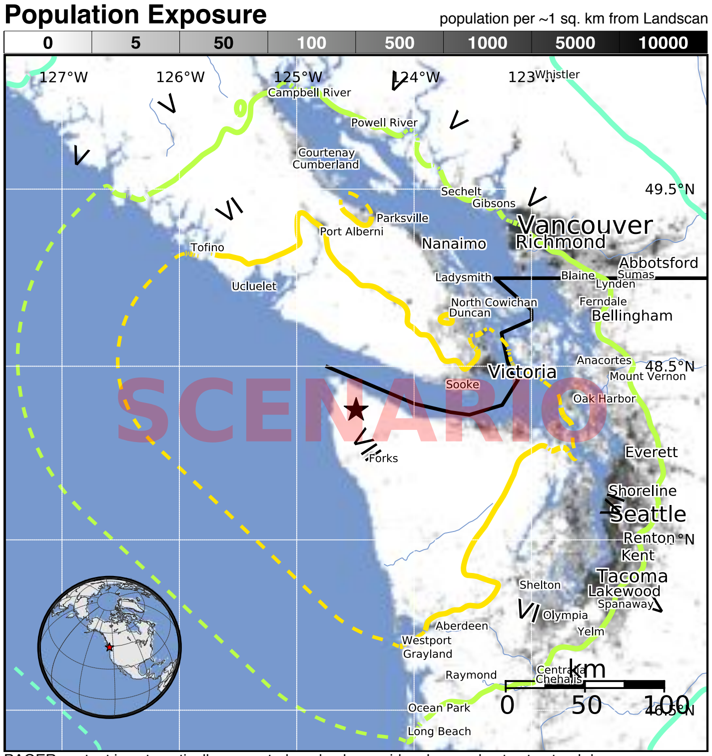
Estimated Population Exposed to Earthquake Shaking

ESTIMATED POPULATION EXPOSURE (k = x1000)		- -*	- -*	2k*	1,850k*	5,754k	546k	3k	0	0
ESTIMATED MODIFIED MERCALLI INTENSITY		I	II-III	IV	V	VI	VII	VIII	IX	X+
PERCEIVED SHAKING		Not felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	Resistant Structures	none	none	none	V. Light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy
	Vulnerable Structures	none	none	none	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy	V. Heavy

*Estimated exposure only includes population within the map area.

Population Exposure

population per ~1 sq. km from Landscan



PAGER content is automatically generated, and only considers losses due to structural damage. Limitations of input data, shaking estimates, and loss models may add uncertainty.
http://earthquake.usgs.gov/pager

Structures:
Overall, the population in this region resides in structures that are resistant to earthquake shaking, though some vulnerable structures exist.

Historical Earthquakes (with MMI levels):

Date (UTC)	Dist. (km)	Mag.	Max MMI(#)	Shaking Deaths
1999-07-03	162	5.8	VII(9k)	0
1993-03-25	384	5.6	VIII(48)	0
2001-02-28	193	6.8	VIII(3k)	0

Recent earthquakes in this area have caused secondary hazards such as landslides and liquefaction that might have contributed to losses.

Selected City Exposure

from GeoNames.org

MMI	City	Population
VIII	**Forks**	**3k**
VII	**Ucluelet**	**2k**
VII	Port Angeles	18k
VII	**Sooke**	**6k**
VII	**Victoria**	**290k**
VII	Ocean Shores	4k
VI	**Olympia**	**45k**
VI	**Richmond**	**182k**
VI	**Seattle**	**569k**
VI	**Vancouver**	**1,838k**
V	**Tacoma**	**197k**

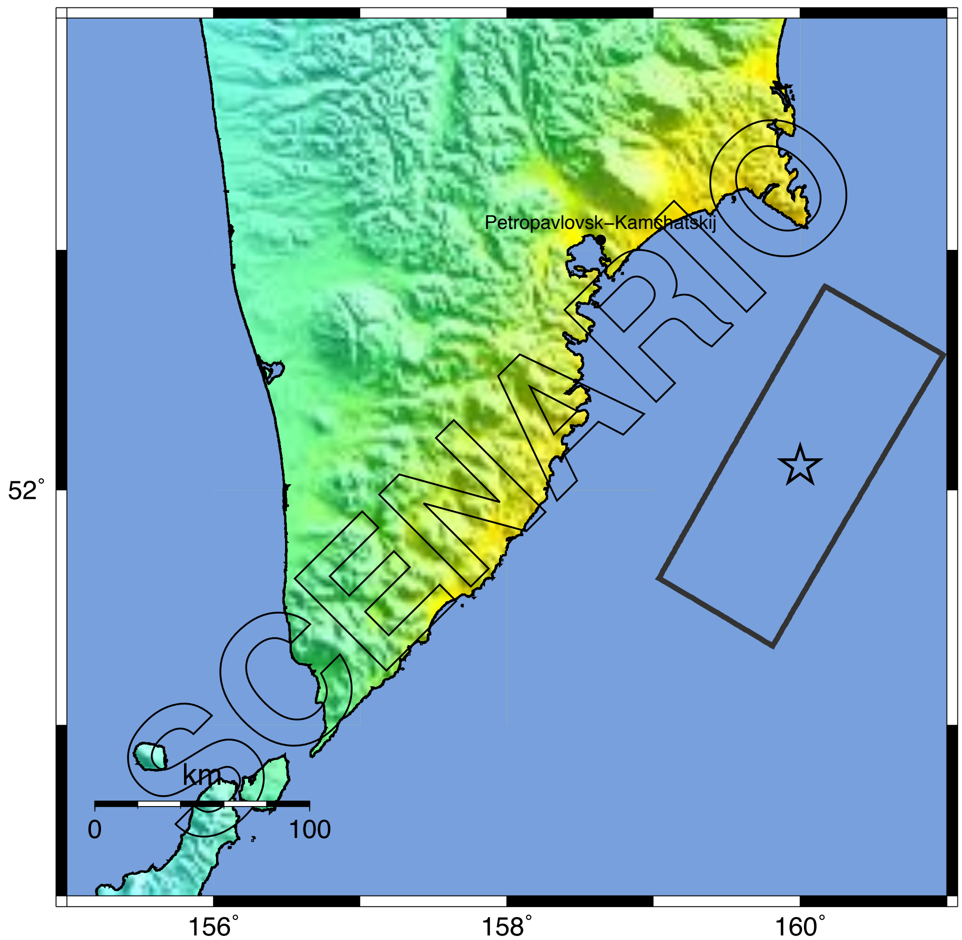
bold cities appear on map (k = x1000)

Event ID: usCanada_Victoria_Subduction_se

–– Earthquake Planning Scenario ––

ShakeMap for Russia_Petropavlovsk_subduction Scenario

Scenario Date: FEB 1 2012 12:00:00 AM GMT M 8.0 N52.10 E160.00 Depth: 25.0km



PLANNING SCENARIO ONLY –– Map Version 1 Processed Tue Sep 27, 2011 12:56:24 PM MDT

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	***<0.1***	***0.5***	***2.4***	***6.7***	***13***	24	44	83	>156
PEAK VEL.(cm/s)	<0.07	0.4	1.9	5.8	***11***	***22***	***43***	***83***	***>160***
INSTRUMENTAL INTENSITY	I	II–III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Wald, et al.; 1999

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Earthquake Shaking **Yellow Alert**

GSN ANSS USAID FROM THE AMERICAN PEOPLE

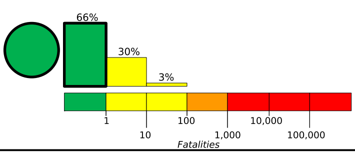
M 8.0, Subduction event offshore Petropavlousk, Russia

Origin Time: Wed 2012-02-01 00:00:00 UTC (11:00:00 local)
Location: 52.10°N 160.00°E Depth: 25 km

PAGER Version 1

Created: 20 minutes after earthquake

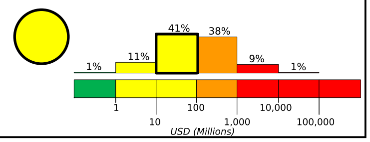
Estimated Fatalities



Yellow alert level for economic losses. Some damage is possible and the impact should be relatively localized. Estimated economic losses are less than 1% of GDP of the Russian Federation. Past events with this alert level have required a local or regional level response.

Green alert level for shaking-related fatalities. There is a low likelihood of casualties.

Estimated Economic Losses



Estimated Population Exposed to Earthquake Shaking

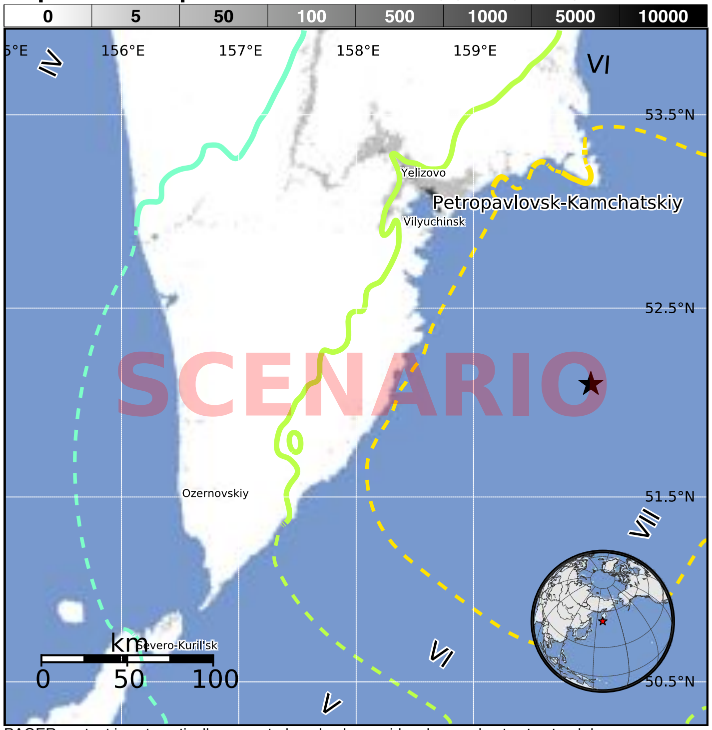
ESTIMATED POPULATION EXPOSURE (k = x1000)		- -*	- -*	2k*	33k*	248k*	592*	0	0	0
ESTIMATED MODIFIED MERCALLI INTENSITY		I	II-III	IV	V	VI	VII	VIII	IX	X+
PERCEIVED SHAKING		Not felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	Resistant Structures	none	none	none	V. Light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy
	Vulnerable Structures	none	none	none	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy	V. Heavy

*Estimated exposure only includes population within the map area.

Population Exposure

population per ~1 sq. km from Landscan

0	5	50	100	500	1000	5000	10000



Structures:
Overall, the population in this region resides in structures that are a mix of vulnerable and earthquake resistant construction. The two model building types that contribute most to fatalities are unreinforced masonry wall with concrete floors and precast moment frame.

Historical Earthquakes (with MMI levels):

Date (UTC)	Dist. (km)	Mag.	Max MMI(#)	Shaking Deaths
2006-08-24	200	6.5	VII(230)	0
1996-01-01	207	6.6	VIII(157)	0
1973-02-28	295	7.2	VIII(776)	0

Selected City Exposure

from GeoNames.org

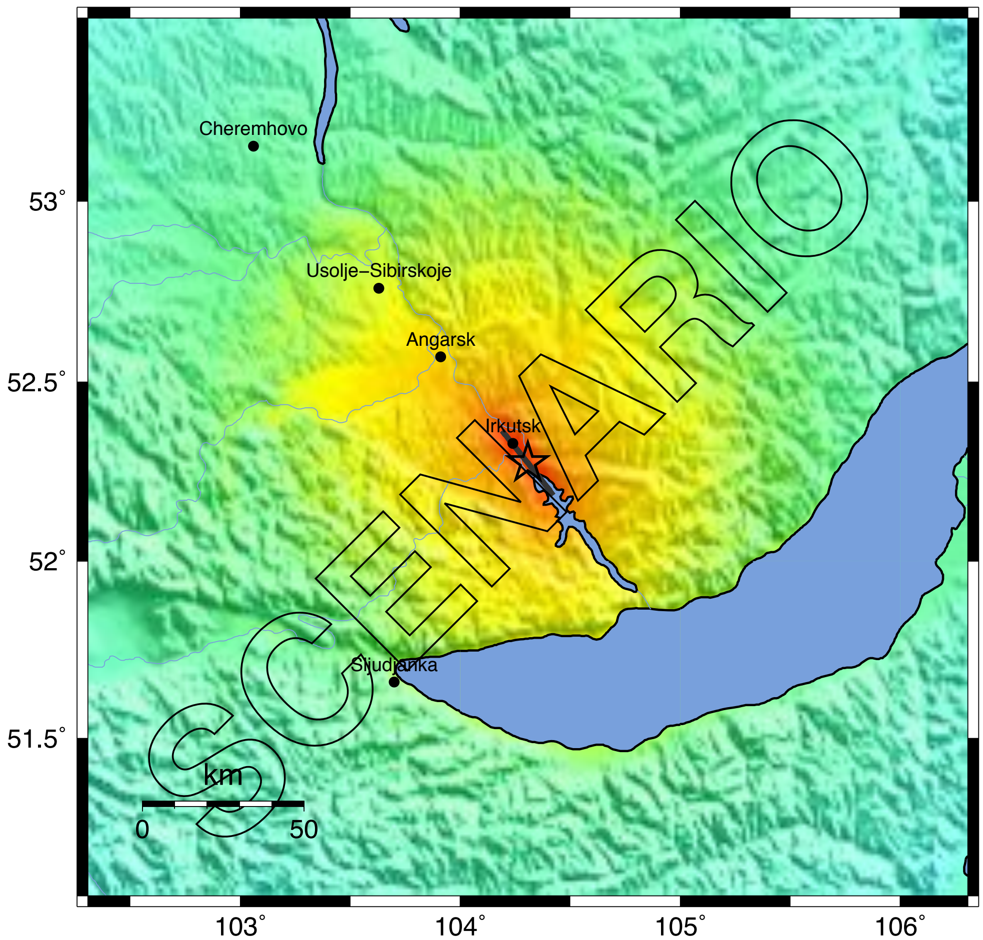
MMI	City	Population
VI	**Vilyuchinsk**	**25k**
VI	Paratunka	2k
VI	Petropavlovsk-K.	187k
V	**Yelizovo**	**41k**
V	**Ozernovskiy**	**3k**
V	**Severo-Kuril'sk**	**2k**

bold cities appear on map (k = x1000)

PAGER content is automatically generated, and only considers losses due to structural damage. Limitations of input data, shaking estimates, and loss models may add uncertainty.
http://earthquake.usgs.gov/pager

Event ID: usRussia_Petropavlovsk_subduction_se

-- Earthquake Planning Scenario --
ShakeMap for Russia_Irkutsk_crustal Scenario
Scenario Date: FEB 1 2012 12:00:00 AM GMT M 6.5 N52.28 E104.31 Depth: 5.0km



PLANNING SCENARIO ONLY -- Map Version 1 Processed Tue Sep 6, 2011 02:17:20 PM MDT

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	*<0.1*	*0.5*	*2.4*	*6.7*	*13*	24	44	83	>156
PEAK VEL.(cm/s)	<0.07	0.4	1.9	5.8	*11*	*22*	*43*	*83*	*>160*
INSTRUMENTAL INTENSITY	I	II–III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Wald, et al.; 1999

USGS science for a changing world

Earthquake Shaking **Red Alert**

USAID FROM THE AMERICAN PEOPLE

GSN ANSS

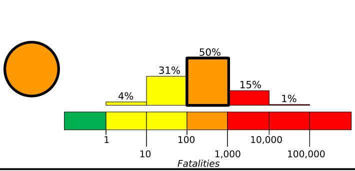
M 6.5, Crustal event under Irkutsk, Russia

Origin Time: Wed 2012-02-01 00:00:00 UTC (09:00:00 local)
Location: 52.28°N 104.31°E Depth: 5 km

PAGER Version 1

Created: 20 minutes after earthquake

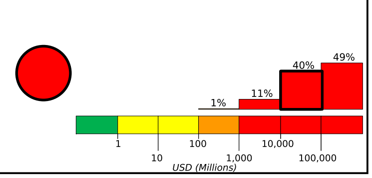
Estimated Fatalities



Red alert level for economic losses. Extensive damage is probable and the disaster is likely widespread. Estimated economic losses are 2-10% GDP of the Russian Federation. Past events with this alert level have required a national or international level response.

Orange alert level for shaking-related fatalities. Significant casualties are likely.

Estimated Economic Losses



Estimated Population Exposed to Earthquake Shaking

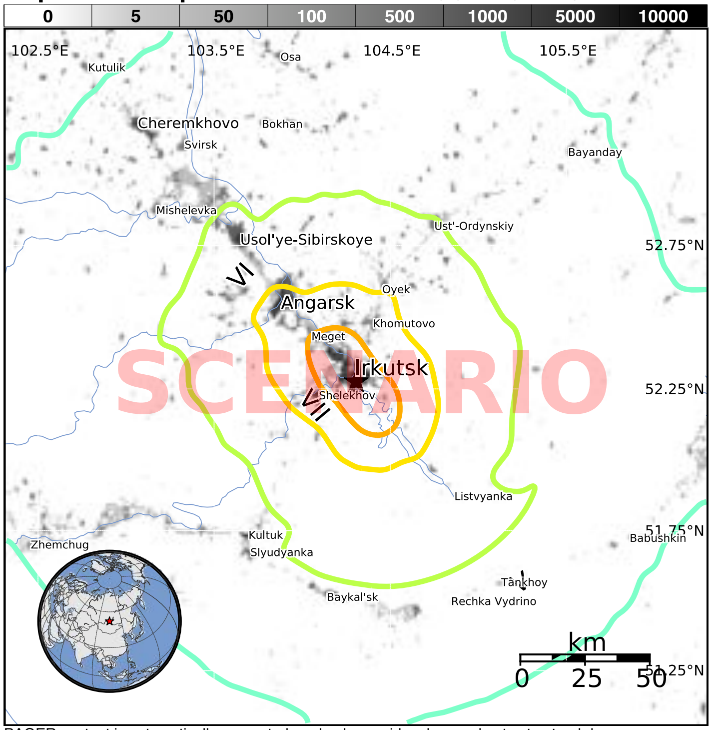
ESTIMATED POPULATION EXPOSURE (k = x1000)		- -*	- -*	25k*	235k	159k	306k	327k	265k	0
ESTIMATED MODIFIED MERCALLI INTENSITY		I	II-III	IV	V	VI	VII	VIII	IX	X+
PERCEIVED SHAKING		Not felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	Resistant Structures	none	none	none	V. Light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy
	Vulnerable Structures	none	none	none	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy	V. Heavy

*Estimated exposure only includes population within the map area.

Population Exposure

population per ~1 sq. km from Landscan

0	5	50	100	500	1000	5000	10000



PAGER content is automatically generated, and only considers losses due to structural damage.
Limitations of input data, shaking estimates, and loss models may add uncertainty.
http://earthquake.usgs.gov/pager

Structures:
Overall, the population in this region resides in structures that are a mix of vulnerable and earthquake resistant construction. The two model building types that contribute most to fatalities are unreinforced masonry wall with concrete floors and precast concrete moment frame.

Historical Earthquakes (with MMI levels):

Date (UTC)	Dist. (km)	Mag.	Max MMI(#)	Shaking Deaths
1999-02-25	86	5.9	VII(387)	0
1989-05-13	247	5.6	VIII(2)	0
1995-06-29	87	5.7	VIII(6)	0

Selected City Exposure

from GeoNames.org

MMI	City	Population
VIII	**Irkutsk**	587k
VIII	**Meget**	8k
VII	**Khomutovo**	5k
VII	**Shelekhov**	47k
VII	**Angarsk**	243k
VII	Kitoy	4k
VI	Usol'ye-S.	86k
VI	**Ust'-Ordynskiy**	15k
V	**Slyudyanka**	19k
V	**Baykal'sk**	16k
V	**Cheremkhovo**	57k

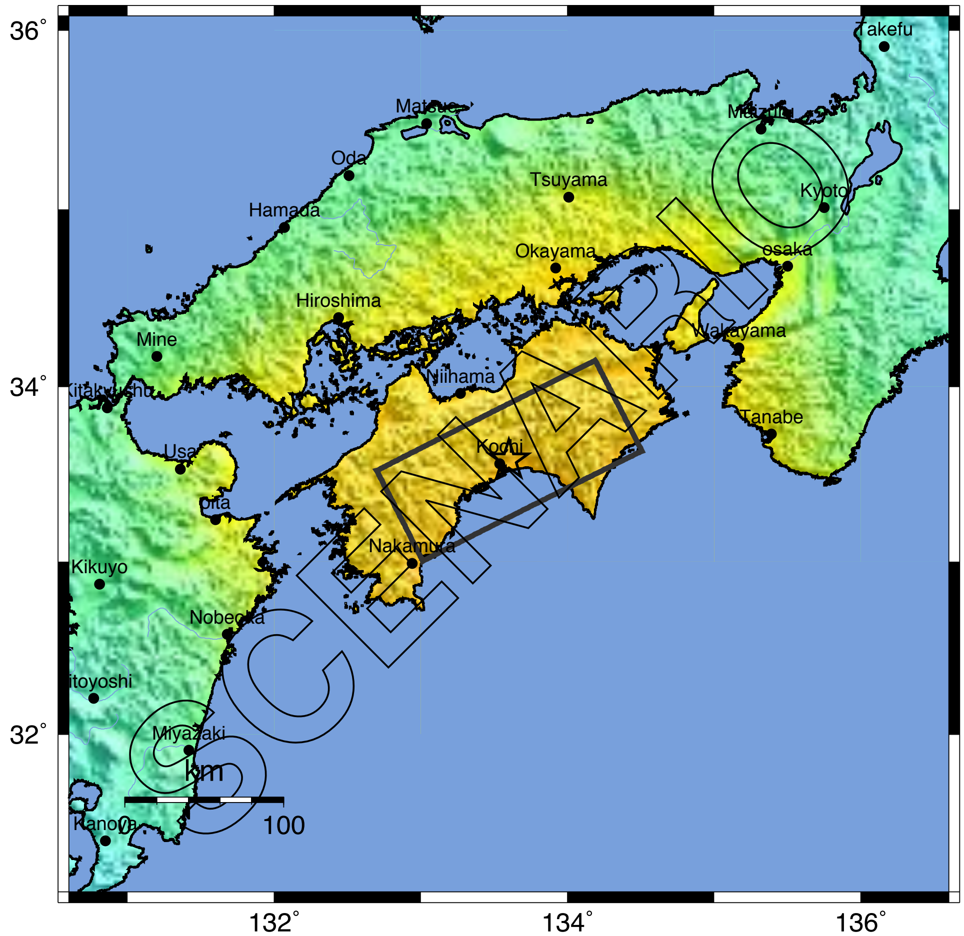
bold cities appear on map (k = x1000)

Event ID: usRussia_Irkutsk_crustal_se

-- Earthquake Planning Scenario --

ShakeMap for Nankai_Trough_Japan Scenario

Scenario Date: FEB 1 2012 12:00:00 AM GMT M 8.0 N33.58 E133.60 Depth: 25.0km



PLANNING SCENARIO ONLY -- Map Version 1 Processed Thu Sep 1, 2011 03:09:32 PM MDT

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	***<0.1***	***0.5***	***2.4***	***6.7***	***13***	24	44	83	>156
PEAK VEL.(cm/s)	<0.07	0.4	1.9	5.8	***11***	***22***	***43***	***83***	***>160***
INSTRUMENTAL INTENSITY	I	II–III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Wald, et al.; 1999

USGS *science for a changing world*

Earthquake Shaking **Orange Alert**

USAID FROM THE AMERICAN PEOPLE

GSN ANSS

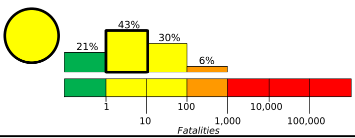
M 8.0, Subduction event offshore south eastern Japan

Origin Time: Wed 2012-02-01 00:00:00 UTC (09:00:00 local)
Location: 33.58^{O}N 133.60^{O}E Depth: 25 km

PAGER Version 1

Created: 20 minutes after earthquake

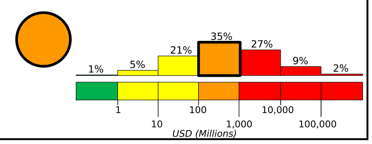
Estimated Fatalities



Orange alert level for economic losses. Significant damage is likely and the disaster is potentially widespread. Estimated economic losses are less than 1% of GDP of Japan. Past events with this alert level have required a regional or national level response.

Yellow alert level for shaking-related fatalities. Some casualties are possible.

Estimated Economic Losses



Estimated Population Exposed to Earthquake Shaking

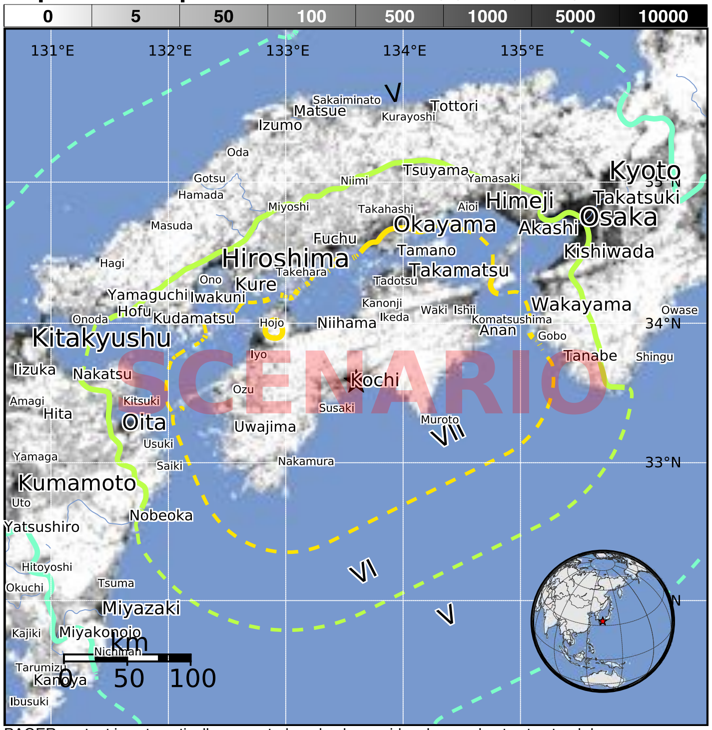
ESTIMATED POPULATION EXPOSURE (k = x1000)		- -*	- -*	1,351k*	18,792k	15,018k	5,192k	103k	0	0
ESTIMATED MODIFIED MERCALLI INTENSITY		I	II-III	IV	V	VI	VII	VIII	IX	X+
PERCEIVED SHAKING		Not felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	Resistant Structures	none	none	none	V. Light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy
	Vulnerable Structures	none	none	none	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy	V. Heavy

*Estimated exposure only includes population within the map area.

Population Exposure

population per ~1 sq. km from Landscan

0	5	50	100	500	1000	5000	10000



PAGER content is automatically generated, and only considers losses due to structural damage.
Limitations of input data, shaking estimates, and loss models may add uncertainty.
http://earthquake.usgs.gov/pager

Structures:
Overall, the population in this region resides in structures that are resistant to earthquake shaking, though some vulnerable structures exist. The two model building types that contribute most to fatalities are traditional wood frame and reinforced concrete frame.

Historical Earthquakes (with MMI levels):

Date (UTC)	Dist. (km)	Mag.	Max MMI(#)	Shaking Deaths
1997-03-26	349	6.1	VIII(31k)	0
2001-03-24	114	6.8	VIII(5k)	2
1995-01-16	171	6.9	IX(1,740k)	6k

Recent earthquakes in this area have caused secondary hazards such as tsunamis, landslides, fires, and liquefaction that might have contributed to losses.

Selected City Exposure

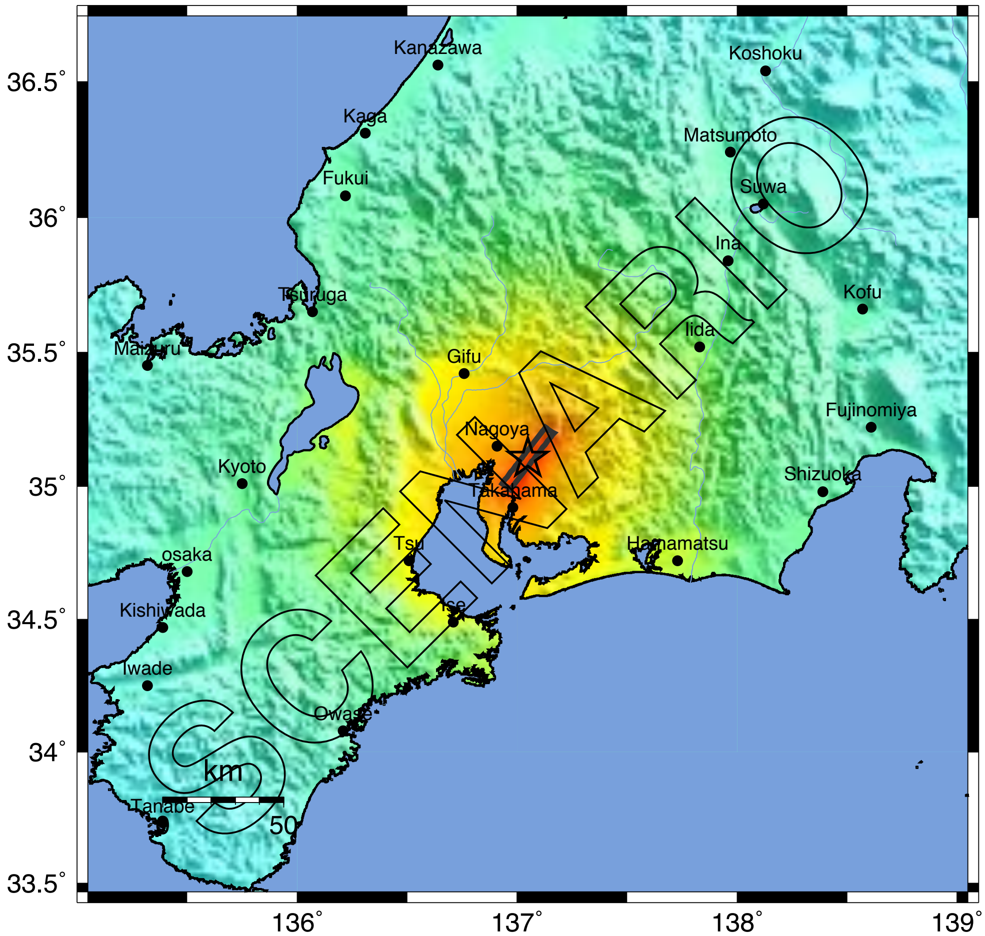
from GeoNames.org

MMI	City	Population
VIII	Aki	20k
VII	**Waki**	**18k**
VII	**Susaki**	**26k**
VII	**Kanonji**	**44k**
VII	Saijo	59k
VII	**Niihama**	**123k**
VI	**Hiroshima**	**1,144k**
VI	Kobe	1,528k
VI	**Osaka**	**2,592k**
V	**Kyoto**	**1,460k**
V	**Kumamoto**	**680k**

bold cities appear on map (k = x1000)

Event ID: usNankai_Trough_Japan_se

-- Earthquake Planning Scenario --
ShakeMap for Nagoya_Japan Scenario
Scenario Date: FEB 1 2012 12:00:00 AM GMT M 6.5 N35.10 E137.05 Depth: 5.0km



PLANNING SCENARIO ONLY -- Map Version 1 Processed Thu Sep 8, 2011 01:37:11 PM MDT

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	**_<0.1_**	**_0.5_**	**_2.4_**	**_6.7_**	**_13_**	24	44	83	>156
PEAK VEL.(cm/s)	<0.07	0.4	1.9	5.8	**_11_**	**_22_**	**_43_**	**_83_**	**_>160_**
INSTRUMENTAL INTENSITY	I	II–III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Wald, et al.; 1999

USGS *science for a changing world*

Earthquake Shaking **Red Alert**

GSN **ANSS** **USAID** FROM THE AMERICAN PEOPLE

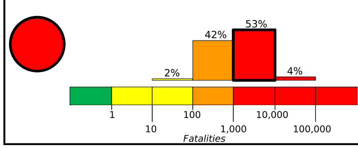
M 6.5, Crustal event East of Nagoya, Japan

Origin Time: Wed 2012-02-01 00:00:00 UTC (09:00:00 local)
Location: 35.10°N 137.05°E Depth: 5 km

PAGER
Version 1

Created: 20 minutes after earthquake

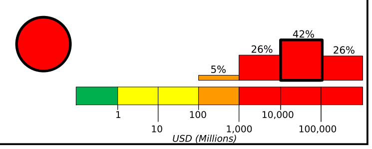
Estimated Fatalities



Red alert for shaking-related fatalities and economic losses. High casualties and extensive damage are probable and the disaster is likely widespread. Past red alerts have required a national or international response.

Estimated economic losses are 0-1% GDP of Japan.

Estimated Economic Losses



Estimated Population Exposed to Earthquake Shaking

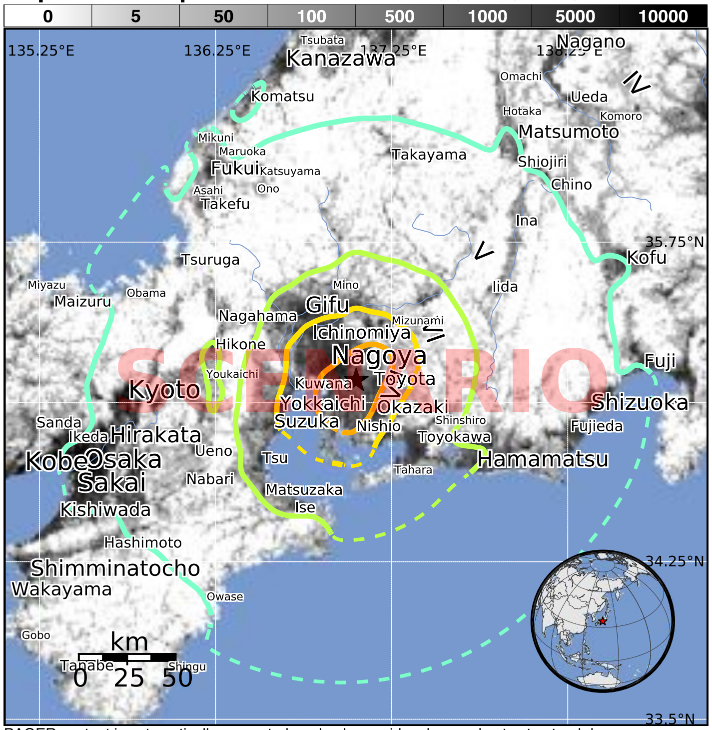
		I	II-III	IV	V	VI	VII	VIII	IX	X+
ESTIMATED POPULATION EXPOSURE (k = x1000)		- -*	- -*	8,850k*	18,656k	4,114k	3,822k	3,162k	348k	0
ESTIMATED MODIFIED MERCALLI INTENSITY		I	II-III	IV	V	VI	VII	VIII	IX	X+
PERCEIVED SHAKING		Not felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	Resistant Structures	none	none	none	V. Light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy
	Vulnerable Structures	none	none	none	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy	V. Heavy

*Estimated exposure only includes population within the map area.

Population Exposure

population per ~1 sq. km from Landscan

0	5	50	100	500	1000	5000	10000



PAGER content is automatically generated, and only considers losses due to structural damage. Limitations of input data, shaking estimates, and loss models may add uncertainty.
http://earthquake.usgs.gov/pager

Structures:
Overall, the population in this region resides in structures that are resistant to earthquake shaking, though some vulnerable structures exist. The two model building types that contribute most to fatalities are traditional wood frame and reinforced concrete frame.

Historical Earthquakes (with MMI levels):

Date (UTC)	Dist. (km)	Mag.	Max MMI(#)	Shaking Deaths
2004-10-23	286	6.6	IX(71k)	16
1974-05-08	168	6.7	IX(30k)	27
1995-01-16	194	6.9	IX(1,740k)	6k

Recent earthquakes in this area have caused secondary hazards such as landslides, fires, and liquefaction that might have contributed to losses.

Selected City Exposure

from GeoNames.org

MMI	City	Population
IX	Obu	78k
IX	Kariya	139k
IX	Miyoshi	57k
IX	Chiryu	67k
VIII	**Toyota**	**362k**
VIII	Seto	134k
VII	**Nagoya**	**2,191k**
V	**Shizuoka**	**702k**
V	**Kyoto**	**1,460k**
V	**Osaka**	**2,592k**
IV	**Kobe**	**1,528k**

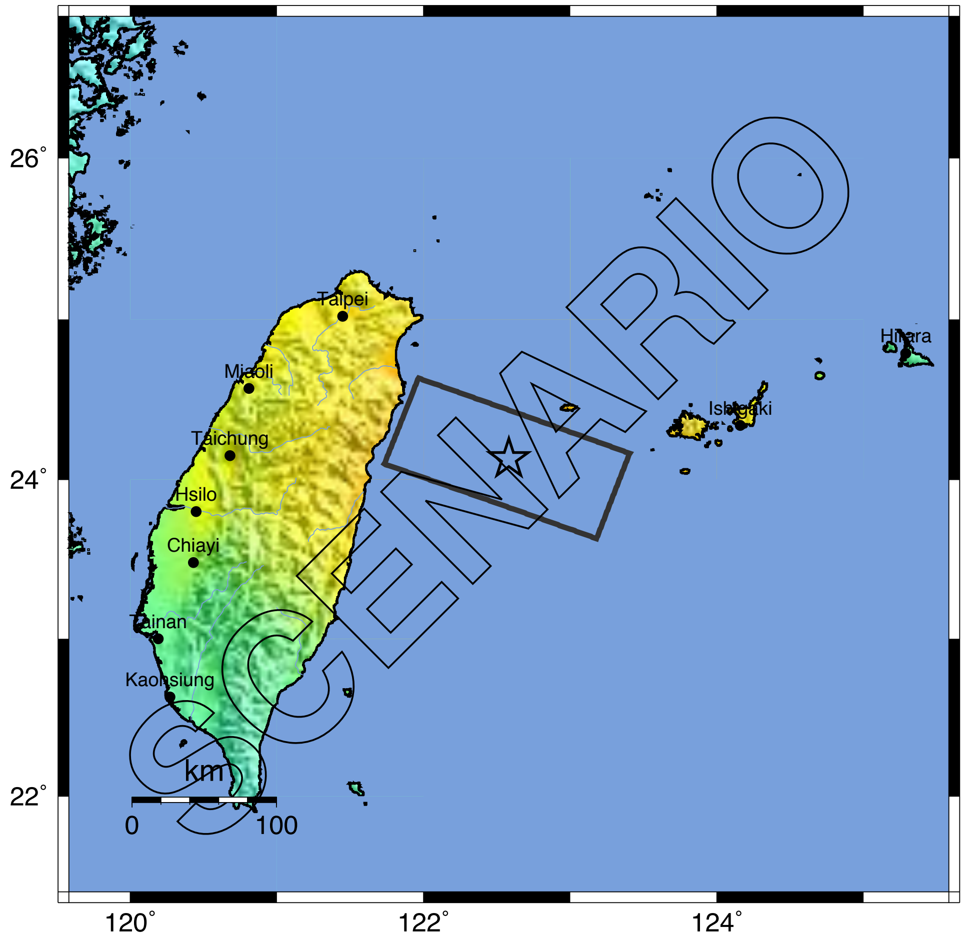
bold cities appear on map (k = x1000)

Event ID: usNagoya_Japan_se

-- Earthquake Planning Scenario --

ShakeMap for Taiwan_Ryukyu_Subduction Scenario

Scenario Date: FEB 1 2012 12:00:00 AM GMT M 8.0 N24.13 E122.58 Depth: 24.8km



PLANNING SCENARIO ONLY -- Map Version 1 Processed Thu Sep 8, 2011 01:16:56 PM MDT

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	*<0.1*	*0.5*	*2.4*	*6.7*	*13*	24	44	83	>156
PEAK VEL.(cm/s)	<0.07	0.4	1.9	5.8	*11*	*22*	*43*	*83*	*>160*
INSTRUMENTAL INTENSITY	I	II–III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Wald, et al.; 1999

USGS
science for a changing world

Earthquake Shaking Yellow Alert

GSN ANSS USAID FROM THE AMERICAN PEOPLE

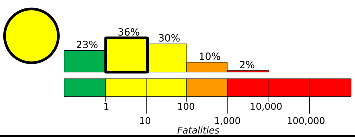
M 8.0, Subduction event offshore eastern Taiwan

Origin Time: Wed 2012-02-01 00:00:00 UTC (08:00:00 local)
Location: 24.13°N 122.58°E Depth: 24 km

PAGER
Version 1

Created: 20 minutes after earthquake

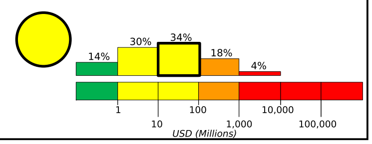
Estimated Fatalities



Yellow alert for shaking-related fatalities and economic losses. Some casualties and damage are possible and the impact should be relatively localized. Past yellow alerts have required a local or regional level response.

Estimated economic losses are less than 1% of GDP of Japan.

Estimated Economic Losses



Estimated Population Exposed to Earthquake Shaking

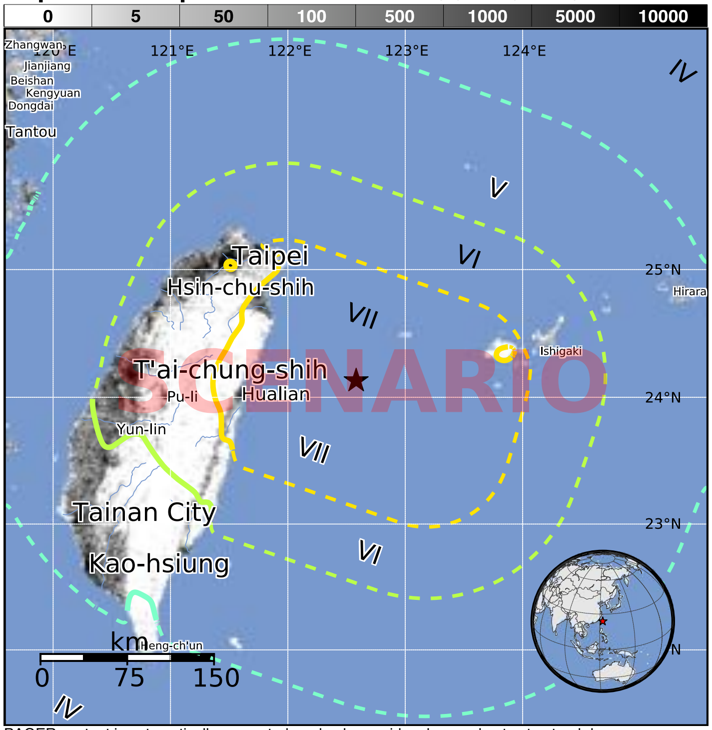
ESTIMATED POPULATION EXPOSURE (k = x1000)		- -*	- -*	1,409k*	7,437k	10,222k	5,583k	7k	0	0
ESTIMATED MODIFIED MERCALLI INTENSITY		I	II-III	IV	V	VI	VII	VIII	IX	X+
PERCEIVED SHAKING		Not felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	Resistant Structures	none	none	none	V. Light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy
	Vulnerable Structures	none	none	none	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy	V. Heavy

*Estimated exposure only includes population within the map area.

Population Exposure

population per ~1 sq. km from Landscan

0	5	50	100	500	1000	5000	10000



PAGER content is automatically generated, and only considers losses due to structural damage.
Limitations of input data, shaking estimates, and loss models may add uncertainty.
http://earthquake.usgs.gov/pager

Structures:
Overall, the population in this region resides in structures that are resistant to earthquake shaking, though some vulnerable structures exist. The two model building types that contribute most to fatalities are unreinforced masonry and nonductile reinforced concrete frame with masonry infill.

Historical Earthquakes (with MMI levels):

Date (UTC)	Dist. (km)	Mag.	Max MMI(#)	Shaking Deaths
1982-12-17	50	6.5	VI(260k)	0
1990-09-30	264	6.1	VII(3)	0
1983-06-24	22	6.6	VII(31)	0

Recent earthquakes in this area have caused secondary hazards such as tsunamis and landslides that might have contributed to losses.

Selected City Exposure

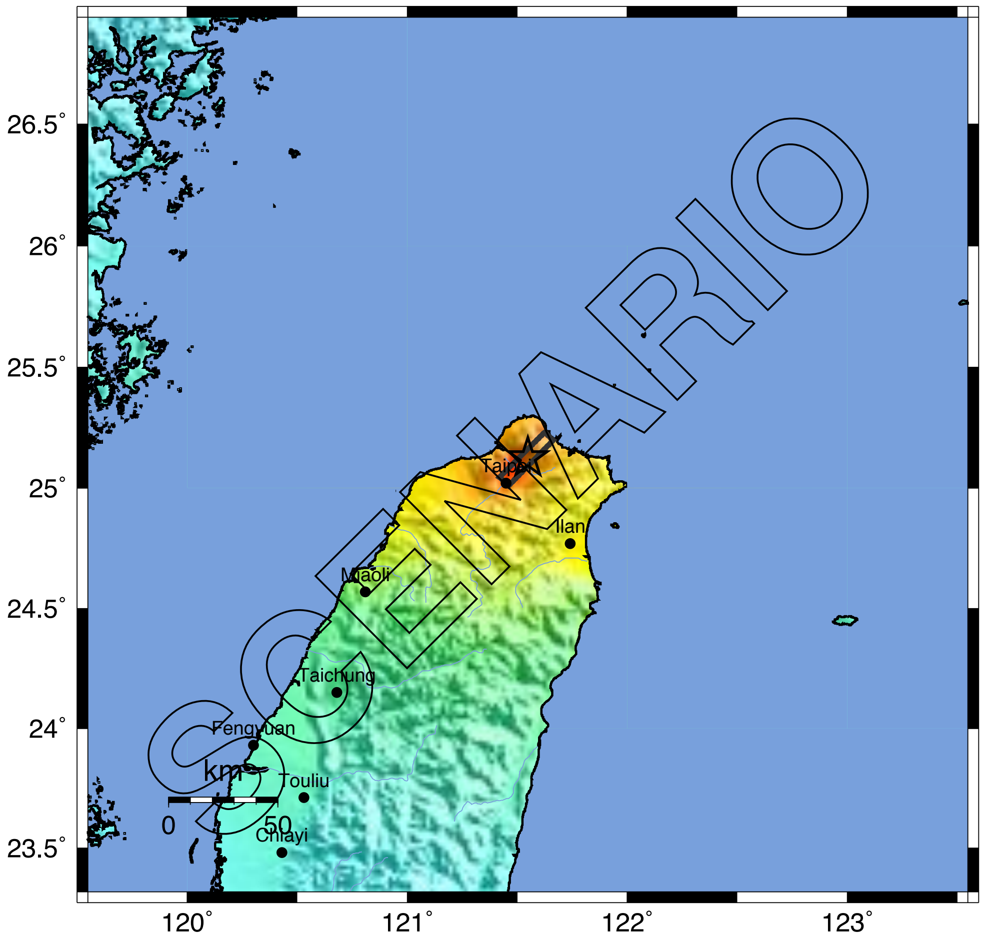
from GeoNames.org

MMI	City	Population
VIII	**Hualian**	**350k**
VII	I-lan	94k
VII	**Taipei**	**7,872k**
VII	Chi-lung	398k
VI	**Pu-li**	**86k**
VI	**Ishigaki**	**45k**
VI	**Hsin-chu-shih**	**404k**
VI	**T'ai-chung-shih**	**1,041k**
V	Taitung City	111k
V	**Tainan City**	**764k**
V	**Kao-hsiung**	**1,520k**

bold cities appear on map (k = x1000)

Event ID: usTaiwan_Ryukyu_Subduction_se

-- Earthquake Planning Scenario --
ShakeMap for Taiwan_Shanchiao_Fault Scenario
Scenario Date: FEB 1 2012 12:00:00 AM GMT M 6.5 N25.13 E121.55 Depth: 5.0km



PLANNING SCENARIO ONLY -- Map Version 1 Processed Tue Sep 27, 2011 12:47:49 PM MDT

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	***<0.1***	***0.5***	***2.4***	***6.7***	***13***	24	44	83	>156
PEAK VEL.(cm/s)	<0.07	0.4	1.9	5.8	***11***	***22***	***43***	***83***	***>160***
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Wald, et al.; 1999

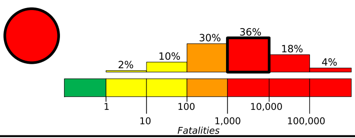
Earthquake Shaking **Red Alert**

M 6.5, Shanchiao Fault, north of Taipei, Taiwan

Origin Time: Wed 2012-02-01 00:00:00 UTC (08:00:00 local)
Location: 25.13°N 121.55°E Depth: 5 km

PAGER
Version 1
Created: 20 minutes after earthquake

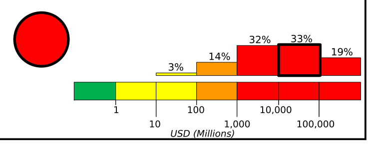
Estimated Fatalities



Red alert for shaking-related fatalities and economic losses. High casualties and extensive damage are probable and the disaster is likely widespread. Past red alerts have required a national or international response.

Estimated economic losses are 1-7% GDP of Taiwan, Province of China.

Estimated Economic Losses



Estimated Population Exposed to Earthquake Shaking

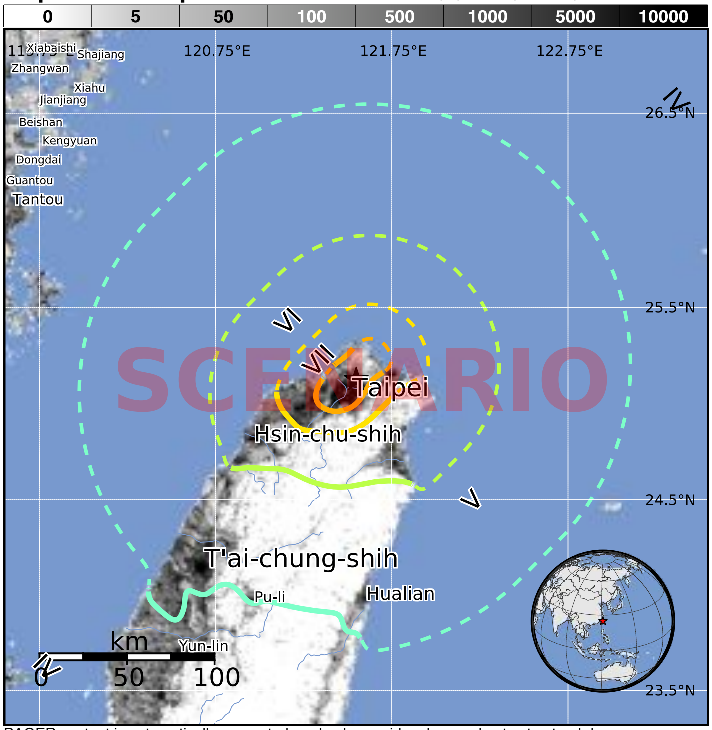
ESTIMATED POPULATION EXPOSURE (k = x1000)		- -*	- -*	4,845k*	4,360k	1,731k	2,156k	5,135k	1,128k	0
ESTIMATED MODIFIED MERCALLI INTENSITY		I	II-III	IV	V	VI	VII	VIII	IX	X+
PERCEIVED SHAKING		Not felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	Resistant Structures	none	none	none	V. Light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy
	Vulnerable Structures	none	none	none	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy	V. Heavy

*Estimated exposure only includes population within the map area.

Population Exposure

population per ~1 sq. km from Landscan

0	5	50	100	500	1000	5000	10000



PAGER content is automatically generated, and only considers losses due to structural damage. Limitations of input data, shaking estimates, and loss models may add uncertainty.
http://earthquake.usgs.gov/pager

Structures:
Overall, the population in this region resides in structures that are resistant to earthquake shaking, though some vulnerable structures exist. The two model building types that contribute most to fatalities are unreinforced masonry and nonductile reinforced concrete frame with masonry infill.

Historical Earthquakes (with MMI levels):

Date (UTC)	Dist. (km)	Mag.	Max MMI(#)	Shaking Deaths
1986-05-20	109	6.2	IX(185k)	1
1986-11-14	129	7.3	VIII(160k)	15
1999-09-20	160	7.6	IX(1,952k)	2k

Recent earthquakes in this area have caused secondary hazards such as landslides that might have contributed to losses.

Selected City Exposure

from GeoNames.org

MMI	City	Population
VIII	**Taipei**	**7,872k**
VII	Chi-lung	398k
VI	I-lan	94k
VI	Ta-hsi-chen	85k
VI	**Hsin-chu-shih**	**404k**
V	**Hualian**	**350k**
V	**T'ai-chung-shih**	**1,041k**
V	**Pu-li**	**86k**
IV	**Yun-lin**	**105k**
IV	**Tantou**	**69k**
IV	**Xiabaishi**	**8k**

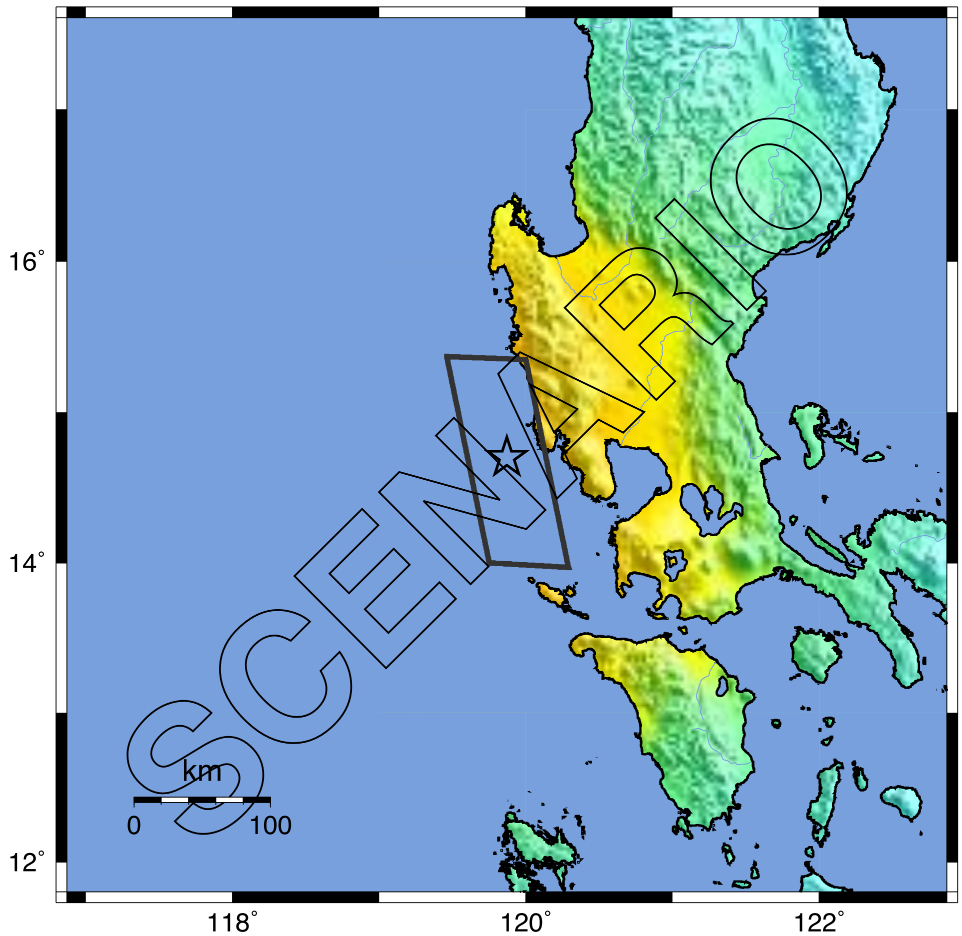
bold cities appear on map (k = x1000)

Event ID: usTaiwan_Shanchiao_Fault_se

-- Earthquake Planning Scenario --

ShakeMap for Manila Scenario

Scenario Date: JAN 1 2012 12:00:00 AM GMT   M 8.0   N14.70 E119.87   Depth: 25.0km



PLANNING SCENARIO ONLY -- Map Version 16 Processed Thu Sep 22, 2011 02:07:08 PM MDT

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	***<0.1***	***0.5***	***2.4***	***6.7***	***13***	24	44	83	>156
PEAK VEL.(cm/s)	<0.07	0.4	1.9	5.8	***11***	***22***	***43***	***83***	***>160***
INSTRUMENTAL INTENSITY	**I**	**II–III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X+**

Scale based upon Wald, et al.; 1999

USGS science for a changing world

Earthquake Shaking Yellow Alert

GSN ANSS USAID FROM THE AMERICAN PEOPLE

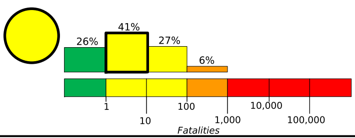
M 8.0, OFFSHORE LUZON

Origin Time: Sun 2012-01-01 12:00:00 UTC (20:00:00 local)
Location: 14.70°N 119.87°E Depth: 25 km

PAGER Version 1

Created: -20461808 seconds after earthquake

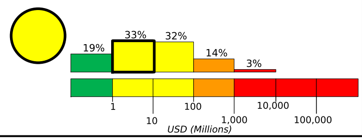
Estimated Fatalities



Yellow alert for shaking-related fatalities and economic losses. Some casualties and damage are possible and the impact should be relatively localized. Past yellow alerts have required a local or regional level response.

Estimated economic losses are less than 1% of GDP of the Philippines.

Estimated Economic Losses



Estimated Population Exposed to Earthquake Shaking

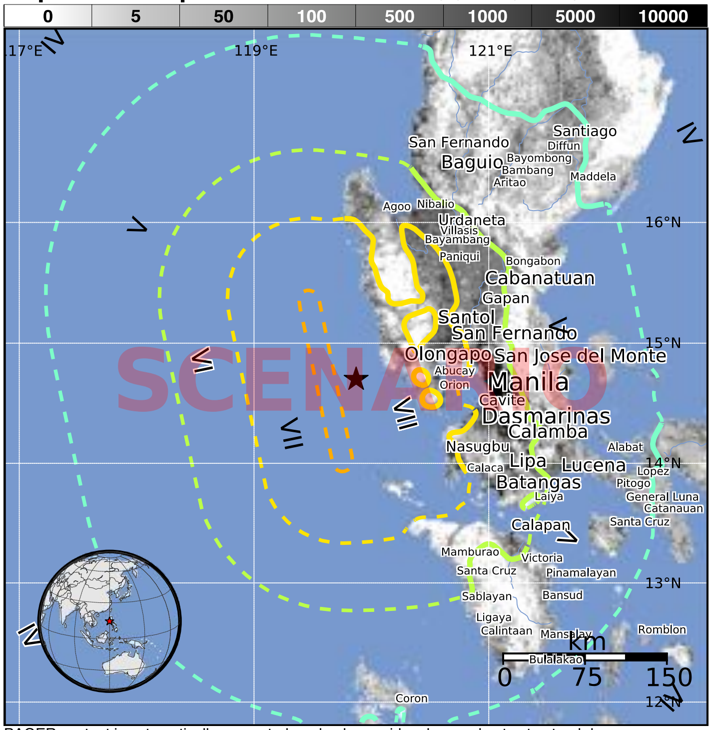
ESTIMATED POPULATION EXPOSURE (k = x1000)		- -*	- -*	2,826k*	6,881k	30,970k	7,349k	3k	0	0
ESTIMATED MODIFIED MERCALLI INTENSITY		I	II-III	IV	V	VI	VII	VIII	IX	X+
PERCEIVED SHAKING		Not felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	Resistant Structures	none	none	none	V. Light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy
	Vulnerable Structures	none	none	none	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy	V. Heavy

*Estimated exposure only includes population within the map area.

Population Exposure

population per ~1 sq. km from Landscan

0	5	50	100	500	1000	5000	10000



PAGER content is automatically generated, and only considers losses due to structural damage. Limitations of input data, shaking estimates, and loss models may add uncertainty.

http://earthquake.usgs.gov/pager

Structures:
Overall, the population in this region resides in structures that are a mix of vulnerable and earthquake resistant construction. The two model building types that contribute most to fatalities are reinforced concrete and heavy wood frame.

Historical Earthquakes (with MMI levels):

Date (UTC)	Dist. (km)	Mag.	Max MMI(#)	Shaking Deaths
2006-03-01	153	5.8	VIII(2k)	0
1973-03-17	347	7.5	VIII(6k)	15
1990-07-16	181	7.7	IX(893k)	2k

Recent earthquakes in this area have caused secondary hazards such as tsunamis, landslides, and liquefaction that might have contributed to losses.

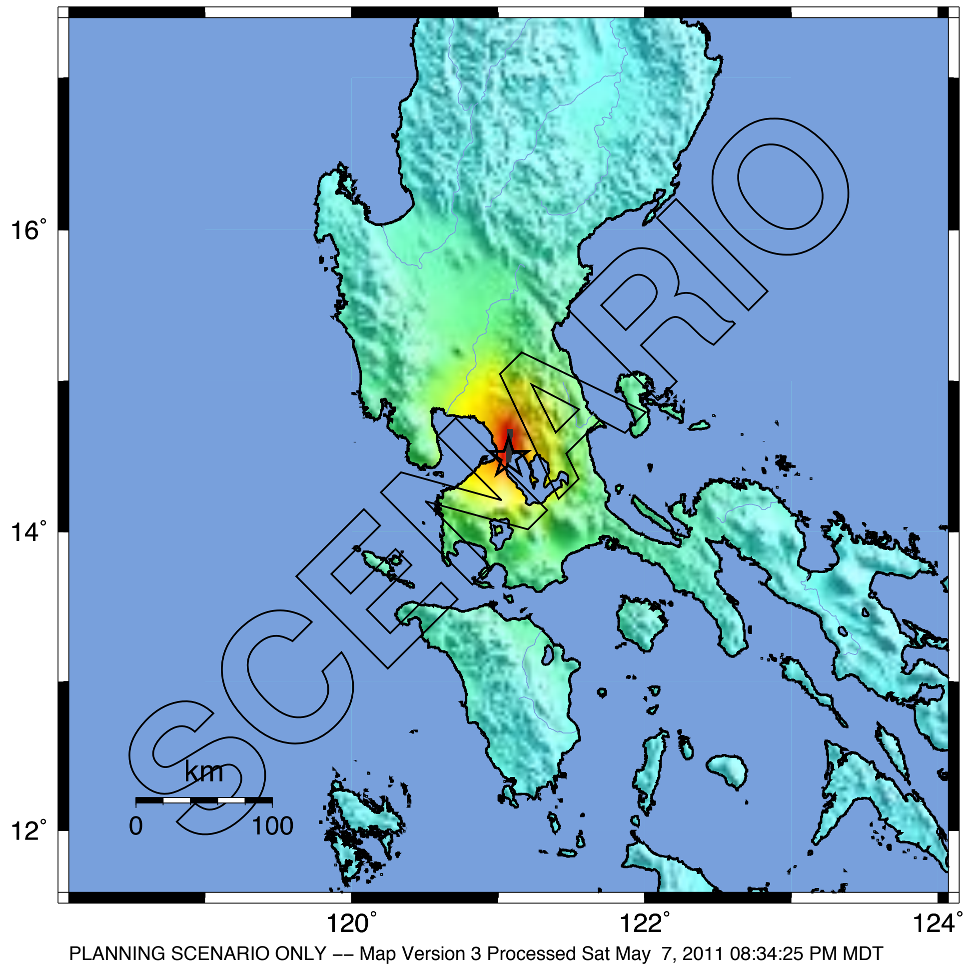
Selected City Exposure

from GeoNames.org

MMI	City	Population
VIII	Cabra	3k
VII	Tangal	3k
VII	Tagbac	4k
VII	Liozon	3k
VII	Bulawen	4k
VII	San Narciso	16k
VI	**Manila**	**10,445k**
VI	Makati	< 1k
VI	Pasig	< 1k
VI	Antipolo	550k
IV	Tabuk	27k

bold cities appear on map (k = x1000)

Event ID: usManila_se



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<0.17	0.17–1.4	1.4–4.0	4.0–9	9–17	17–32	32–61	61–114	>114
PEAK VEL.(cm/s)	<0.12	0.12–1.1	1.1–3.4	3.4–8	8–16	16–31	31–59	59–115	>115
INSTRUMENTAL INTENSITY	I	II–III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Wald, et al.; 1999

science for a changing world

Earthquake Shaking **Red Alert**

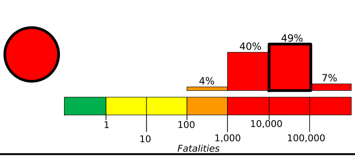
M 6.5, M6.5 Metro Manila

Origin Time: Sun 2012-01-01 12:00:00 UTC (20:00:00 local)
Location: 14.49^{O}N 121.07^{O}E Depth: 5 km

PAGER Version 1

Created: 20 minutes after earthquake

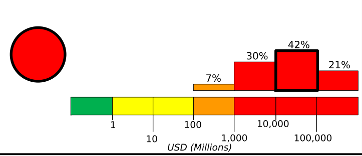
Estimated Fatalities



Red alert for shaking-related fatalities and economic losses. High casualties and extensive damage are probable and the disaster is likely widespread. Past red alerts have required a national or international response.

Estimated economic losses are 4-20% GDP of the Philippines.

Estimated Economic Losses



Estimated Population Exposed to Earthquake Shaking

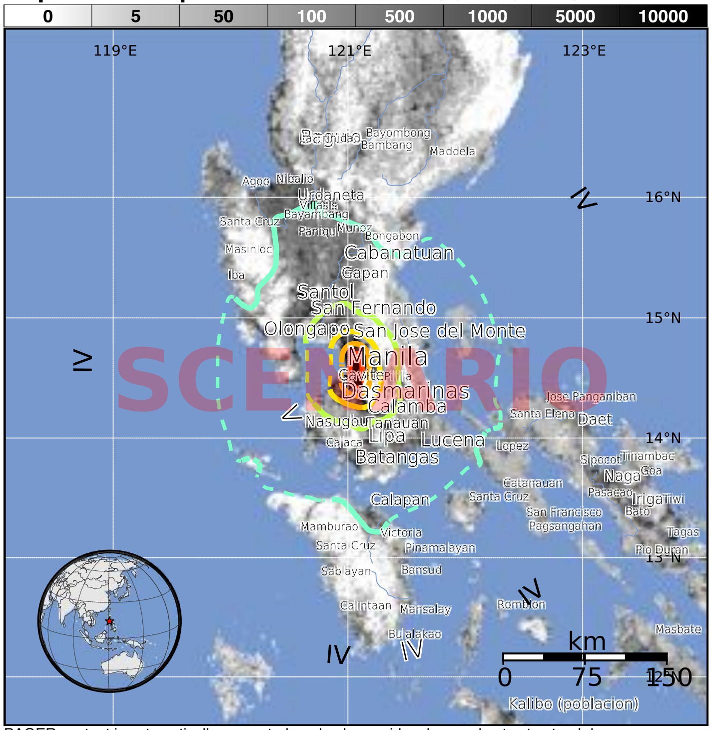
ESTIMATED POPULATION EXPOSURE (k = x1000)		- -*	175*	16,435k	12,904k	3,977k	4,249k	8,914k	6,876k	0
ESTIMATED MODIFIED MERCALLI INTENSITY		I	II-III	IV	V	VI	VII	VIII	IX	X+
PERCEIVED SHAKING		Not felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	Resistant Structures	none	none	none	V. Light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy
	Vulnerable Structures	none	none	none	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy	V. Heavy

*Estimated exposure only includes population within the map area.

Population Exposure

population per ~1 sq. km from Landscan

0 | 5 | 50 | 100 | 500 | 1000 | 5000 | 10000



Structures:
Overall, the population in this region resides in structures that are a mix of vulnerable and earthquake resistant construction. The predominant vulnerable building types are reinforced concrete and heavy wood frame construction.

Historical Earthquakes (with MMI levels):

Date (UTC)	Dist. (km)	Mag.	Max MMI(#)	Shaking Deaths
1990-06-14	360	7.1	IX(49k)	4
1994-11-14	106	7.1	VIII(1,086k)	78
1990-07-16	138	7.7	IX(893k)	2k

Recent earthquakes in this area have caused secondary hazards such as landslides and liquefaction that might have contributed to losses.

Selected City Exposure

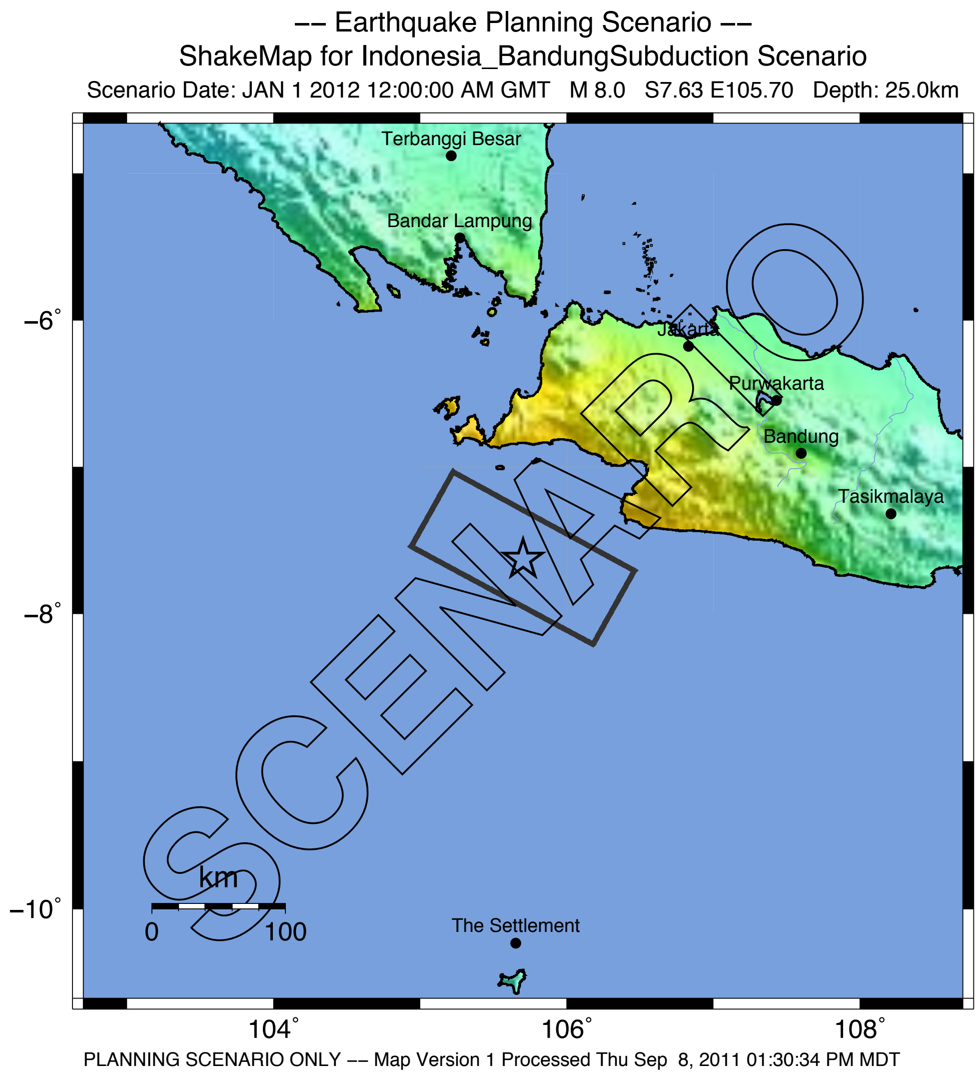
from GeoNames.org

MMI	City	Population
IX	Pasig	< 1k
IX	Malanday	22k
IX	Makati	< 1k
IX	San Mateo	134k
IX	Cainta	283k
VIII	Angono	87k
VIII	**Manila**	**10,445k**
VIII	Bacoor	357k
VIII	Antipolo	550k
VII	**Dasmarinas**	**442k**

bold cities appear on map (k = x1000)

PAGER content is automatically generated, and only considers losses due to structural damage. Limitations of input data, shaking estimates, and loss models may add uncertainty.
http://earthquake.usgs.gov/pager

Event ID: usMarikina_se



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	**<0.1**	**0.5**	**2.4**	**6.7**	**13**	24	44	83	>156
PEAK VEL.(cm/s)	<0.07	0.4	1.9	5.8	**11**	**22**	**43**	**83**	**>160**
INSTRUMENTAL INTENSITY	I	II–III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Wald, et al.; 1999

Earthquake Shaking Yellow Alert

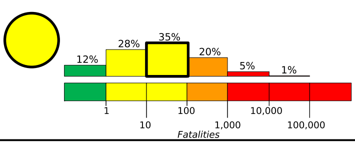
PAGER Version 1

M 8.0, Subduction event WSW of Bandung

Origin Time: Sun 2012-01-01 00:00:00 UTC (07:00:00 local)
Location: 7.63°S 105.70°E Depth: 25 km

Created: 20 minutes after earthquake

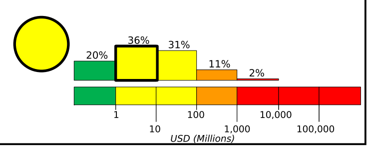
Estimated Fatalities



Yellow alert for shaking-related fatalities and economic losses. Some casualties and damage are possible and the impact should be relatively localized. Past yellow alerts have required a local or regional level response.

Estimated economic losses are less than 1% of GDP of Indonesia.

Estimated Economic Losses



Estimated Population Exposed to Earthquake Shaking

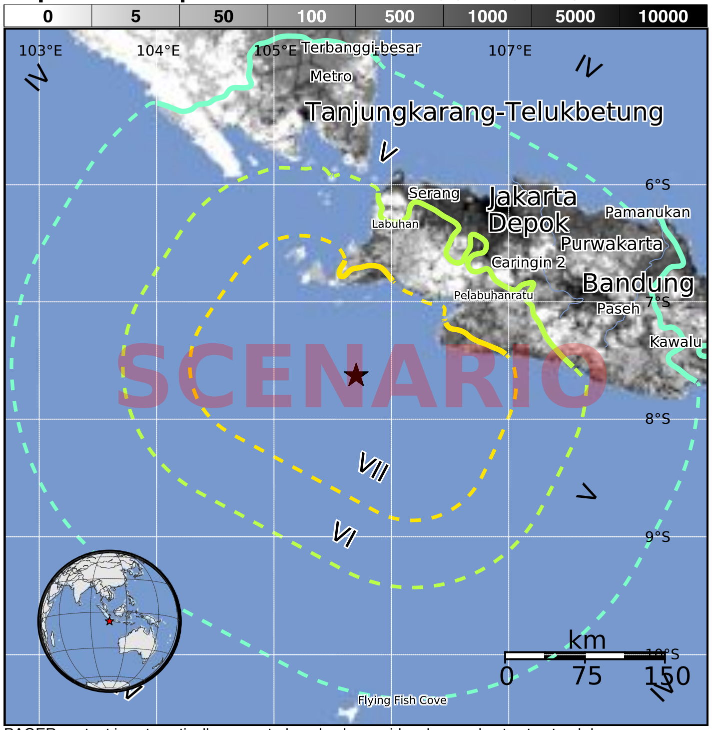
ESTIMATED POPULATION EXPOSURE (k = x1000)		- -*	- -*	3,863k*	54,342k	8,276k	1,601k	0	0	0
ESTIMATED MODIFIED MERCALLI INTENSITY		I	II-III	IV	V	VI	VII	VIII	IX	X+
PERCEIVED SHAKING		Not felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	Resistant Structures	none	none	none	V. Light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy
	Vulnerable Structures	none	none	none	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy	V. Heavy

*Estimated exposure only includes population within the map area.

Population Exposure

population per ~1 sq. km from Landscan

0	5	50	100	500	1000	5000	10000



PAGER content is automatically generated, and only considers losses due to structural damage.
Limitations of input data, shaking estimates, and loss models may add uncertainty.
http://earthquake.usgs.gov/pager

Structures:
Overall, the population in this region resides in structures that are vulnerable to earthquake shaking, though some resistant structures exist. The two model building types that contribute most to fatalities are unreinforced brick masonry and nonductile reinforced concrete frame with masonry infill.

Historical Earthquakes (with MMI levels):

Date (UTC)	Dist. (km)	Mag.	Max MMI(#)	Shaking Deaths
1988-08-17	153	6.0	VII(363k)	0
1999-12-21	89	6.4	VII(817k)	5
1979-11-02	272	6.5	VII(483k)	23

Recent earthquakes in this area have caused secondary hazards such as tsunamis and landslides that might have contributed to losses.

Selected City Exposure

from GeoNames.org

MMI	City	Population
VI	**Pelabuhanratu**	**43k**
VI	**Labuhan**	**34k**
VI	Cicurug	89k
VI	Rangkasbitung	127k
VI	Sukabumi	276k
VI	Ciranjang-hilir	78k
V	**Bandung**	**1,700k**
V	**Jakarta**	**8,540k**
V	Bekasi	1,520k
V	Tanjungkarang-T.	800k
IV	**Flying Fish Cove**	**< 1k**

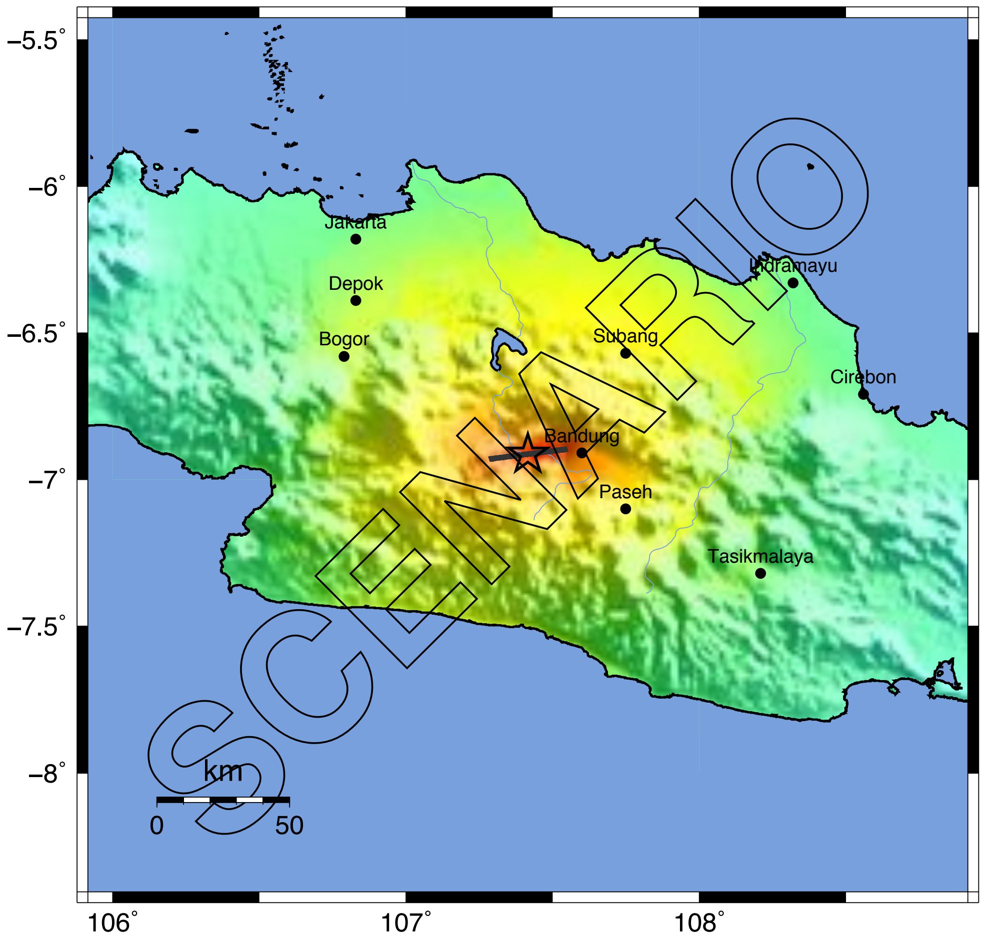
bold cities appear on map (k = x1000)

Event ID: usIndonesia_BandungSubduction_se

-- Earthquake Planning Scenario --

ShakeMap for Indonesia_SSBandung Scenario

Scenario Date: FEB 1 2012 12:00:00 AM GMT M 6.5 S6.91 E107.42 Depth: 5.0km



PLANNING SCENARIO ONLY -- Map Version 1 Processed Tue Sep 6, 2011 02:32:31 PM MDT

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<0.1	0.5	2.4	6.7	13	24	44	83	>156
PEAK VEL.(cm/s)	<0.07	0.4	1.9	5.8	11	22	43	83	>160
INSTRUMENTAL INTENSITY	I	II–III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Wald, et al.; 1999

USGS
science for a changing world

Earthquake Shaking — Red Alert

GSN ANSS — USAID FROM THE AMERICAN PEOPLE

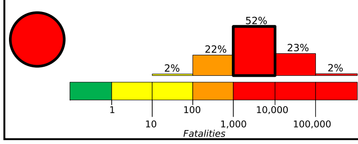
M 6.5, Strike Slip event west of Bandung

Origin Time: Wed 2012-02-01 00:00:00 UTC (07:00:00 local)
Location: 6.91°S 107.42°E Depth: 5 km

PAGER Version 1

Created: 20 minutes after earthquake

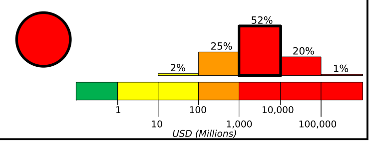
Estimated Fatalities



Red alert for shaking-related fatalities and economic losses. High casualties and extensive damage are probable and the disaster is likely widespread. Past red alerts have required a national or international response.

Estimated economic losses are 0-1% GDP of Indonesia.

Estimated Economic Losses



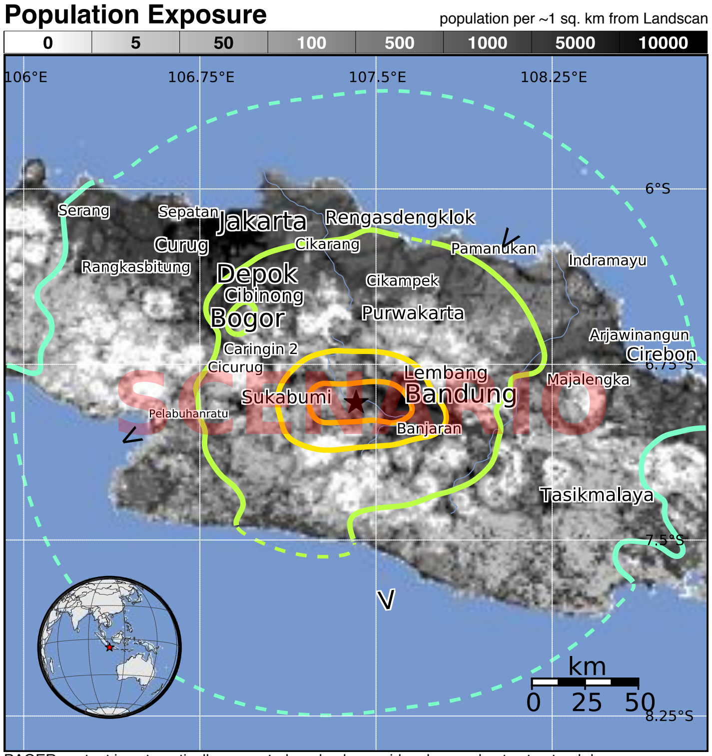
Estimated Population Exposed to Earthquake Shaking

ESTIMATED POPULATION EXPOSURE (k = x1000)		- -*	- -*	2,160k*	39,234k	14,507k	3,604k	3,669k	340k	0
ESTIMATED MODIFIED MERCALLI INTENSITY		I	II-III	IV	V	VI	VII	VIII	IX	X+
PERCEIVED SHAKING		Not felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	Resistant Structures	none	none	none	V. Light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy
	Vulnerable Structures	none	none	none	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy	V. Heavy

*Estimated exposure only includes population within the map area.

Population Exposure

population per ~1 sq. km from Landscan



PAGER content is automatically generated, and only considers losses due to structural damage. Limitations of input data, shaking estimates, and loss models may add uncertainty.
http://earthquake.usgs.gov/pager

Structures:
Overall, the population in this region resides in structures that are vulnerable to earthquake shaking, though some resistant structures exist. The two model building types that contribute most to fatalities are unreinforced brick masonry and nonductile reinforced concrete frame with masonry infill.

Historical Earthquakes (with MMI levels):

Date (UTC)	Dist. (km)	Mag.	Max MMI(#)	Shaking Deaths
2000-10-25	210	6.8	VIII(264k)	0
1979-11-02	124	6.5	VII(483k)	23
2006-05-26	343	6.4	IX(932k)	6k

Selected City Exposure

from GeoNames.org

MMI	City	Population
VIII	Cimahi	494k
VIII	Margahayu	83k
VIII	**Bandung**	**1,700k**
VIII	Ciranjang-hilir	78k
VIII	Padalarang	125k
VII	**Lembang**	**183k**
VI	**Bogor**	**800k**
V	**Depok**	**1,198k**
V	Bekasi	1,520k
V	**Jakarta**	**8,540k**
V	Tangerang	1,372k

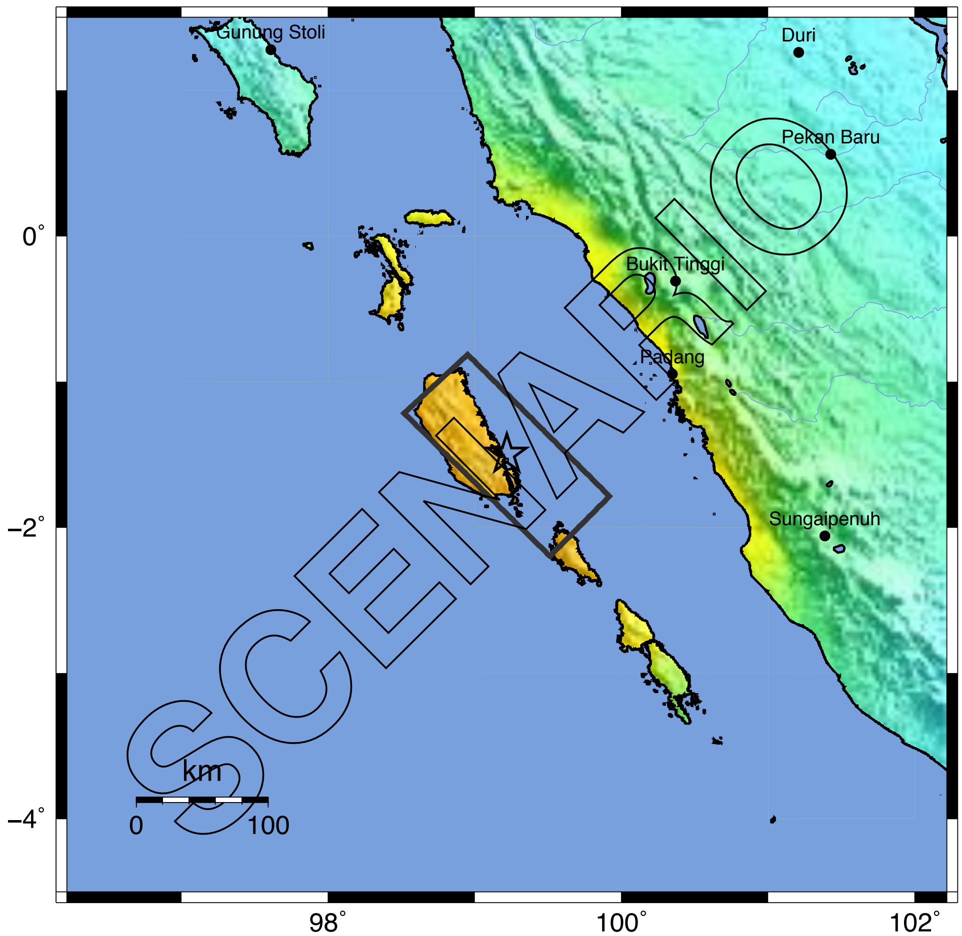
bold cities appear on map (k = x1000)

Event ID: usIndonesia_SSBandung_se

-- Earthquake Planning Scenario --

ShakeMap for Indonesia_PadangSubduction Scenario

Scenario Date: JAN 1 2012 12:00:00 AM GMT   M 8.0   S1.50 E99.22   Depth: 25.0km



PLANNING SCENARIO ONLY -- Map Version 1 Processed Tue Sep 27, 2011 12:41:13 PM MDT

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	*<0.1*	*0.5*	*2.4*	*6.7*	*13*	24	44	83	>156
PEAK VEL.(cm/s)	<0.07	0.4	1.9	5.8	*11*	*22*	*43*	*83*	*>160*
INSTRUMENTAL INTENSITY	I	II–III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Wald, et al.; 1999

Earthquake Shaking Green Alert

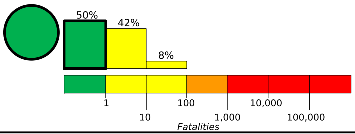
M 8.0, Subduction event offshore of Padang

Origin Time: Sun 2012-01-01 00:00:00 UTC (07:00:00 local)
Location: 1.50°S 99.22°E Depth: 25 km
FOR TSUNAMI INFORMATION, SEE: tsunami.noaa.gov

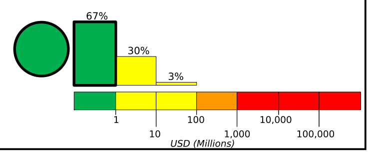
PAGER Version 1
Created: 20 minutes after earthquake

Estimated Fatalities

Green alert for shaking-related fatalities and economic losses. There is a low likelihood of casualties and damage.



Estimated Economic Losses



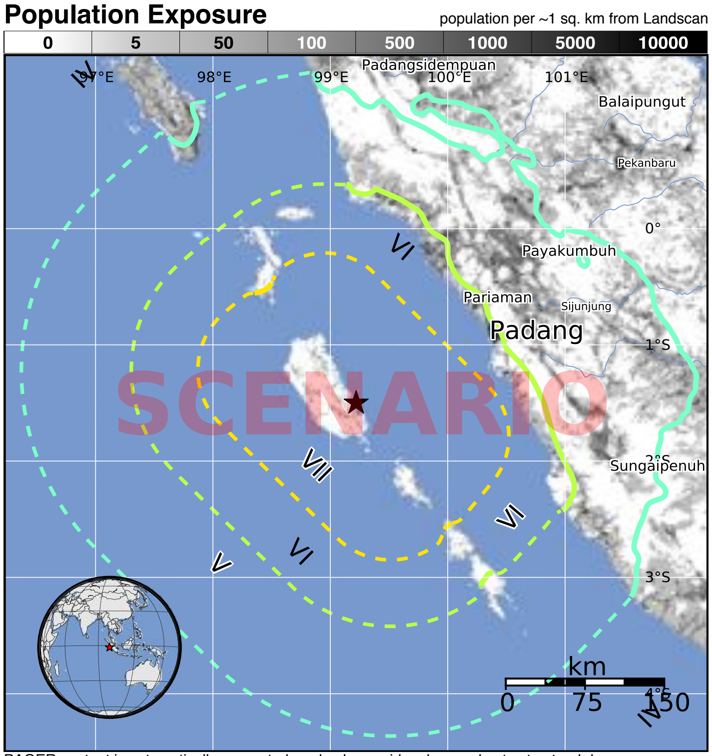
Estimated Population Exposed to Earthquake Shaking

ESTIMATED POPULATION EXPOSURE (k = x1000)		- -*	- -*	4,604k*	4,316k	2,410k	50k	1k	0	0
ESTIMATED MODIFIED MERCALLI INTENSITY		I	II-III	IV	V	VI	VII	VIII	IX	X+
PERCEIVED SHAKING		Not felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	Resistant Structures	none	none	none	V. Light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy
	Vulnerable Structures	none	none	none	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy	V. Heavy

*Estimated exposure only includes population within the map area.

Population Exposure

population per ~1 sq. km from Landscan



PAGER content is automatically generated, and only considers losses due to structural damage. Limitations of input data, shaking estimates, and loss models may add uncertainty.
http://earthquake.usgs.gov/pager

Structures:
Overall, the population in this region resides in structures that are vulnerable to earthquake shaking, though some resistant structures exist.

Historical Earthquakes (with MMI levels):

Date (UTC)	Dist. (km)	Mag.	Max MMI(#)	Shaking Deaths
1987-04-28	397	5.7	VIII(1k)	0
2006-12-17	243	5.8	VII(72k)	7
1995-10-06	254	6.7	VIII(41k)	84

Recent earthquakes in this area have caused secondary hazards such as landslides that might have contributed to losses.

Selected City Exposure

from GeoNames.org

MMI	City	Population
VI	**Padang**	**840k**
VI	**Pariaman**	**92k**
VI	Solok	48k
V	Bukittinggi	99k
V	**Payakumbuh**	**122k**
V	**Sijunjung**	**28k**
V	**Sungaipenuh**	**96k**
IV	**Padangsidempuan**	**101k**
IV	**Pekanbaru**	**< 1k**
IV	**Balaipungut**	**56k**

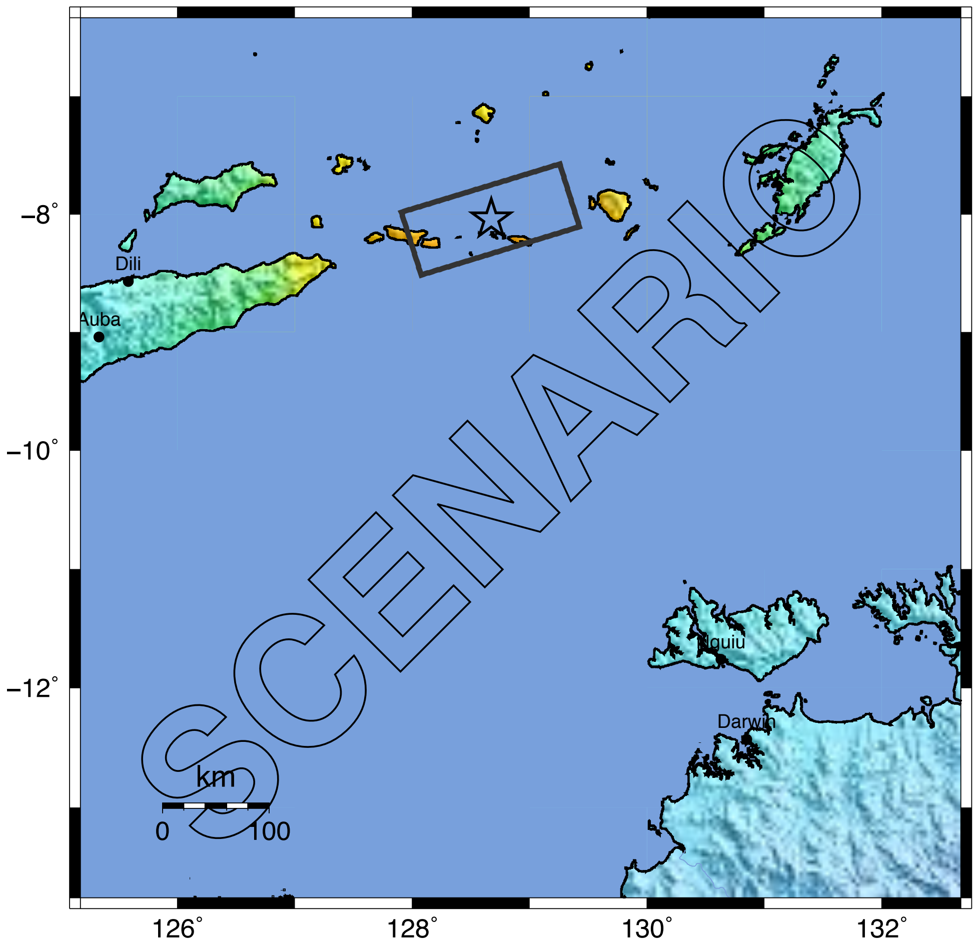
bold cities appear on map (k = x1000)

Event ID: usIndonesia_PadangSubduction_se

–– Earthquake Planning Scenario ––

ShakeMap for North_of_Australia Scenario

Scenario Date: FEB 1 2012 12:00:00 AM GMT   M 8.0   S8.04 E128.67   Depth: 25.0km



PLANNING SCENARIO ONLY –– Map Version 1 Processed Tue Sep 27, 2011 01:21:04 PM MDT

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	***<0.1***	***0.5***	***2.4***	***6.7***	***13***	24	44	83	>156
PEAK VEL.(cm/s)	<0.07	0.4	1.9	5.8	***11***	***22***	***43***	***83***	***>160***
INSTRUMENTAL INTENSITY	I	II–III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Wald, et al.; 1999

USGS
science for a changing world

Earthquake Shaking Yellow Alert

GSN ANSS USAID FROM THE AMERICAN PEOPLE

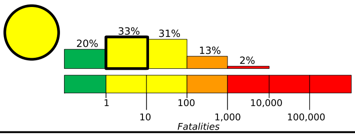
M 8.0, Subduction event north of Darwin

Origin Time: Wed 2012-02-01 00:00:00 UTC (09:00:00 local)
Location: 8.04°S 128.67°E Depth: 25 km

PAGER Version 1

Created: 20 minutes after earthquake

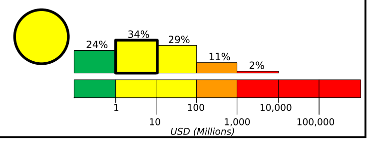
Estimated Fatalities



Yellow alert for shaking-related fatalities and economic losses. Some casualties and damage are possible and the impact should be relatively localized. Past yellow alerts have required a local or regional level response.

Estimated economic losses are less than 1% of GDP of Indonesia.

Estimated Economic Losses



Estimated Population Exposed to Earthquake Shaking

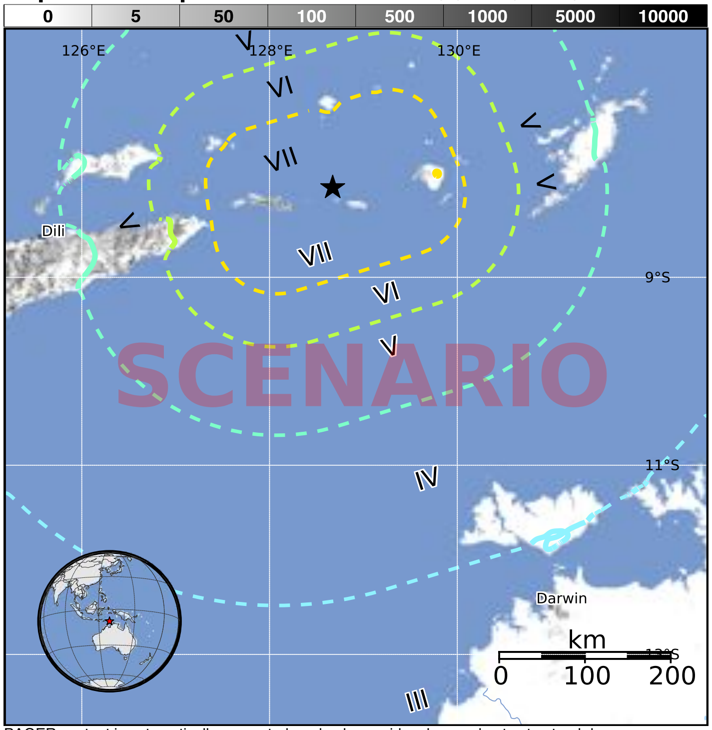
ESTIMATED POPULATION EXPOSURE (k = x1000)		- -*	130k*	797k*	354k*	63k	56k	19k	0	0
ESTIMATED MODIFIED MERCALLI INTENSITY		I	II-III	IV	V	VI	VII	VIII	IX	X+
PERCEIVED SHAKING		Not felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	Resistant Structures	none	none	none	V. Light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy
	Vulnerable Structures	none	none	none	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy	V. Heavy

*Estimated exposure only includes population within the map area.

Population Exposure

population per ~1 sq. km from Landscan

0	5	50	100	500	1000	5000	10000



PAGER content is automatically generated, and only considers losses due to structural damage.
Limitations of input data, shaking estimates, and loss models may add uncertainty.
http://earthquake.usgs.gov/pager

Structures:
Overall, the population in this region resides in structures that are vulnerable to earthquake shaking, though some resistant structures exist. The two model building types that contribute most to fatalities are unreinforced brick masonry and nonductile reinforced concrete frame with masonry infill.

Historical Earthquakes (with MMI levels):

Date (UTC)	Dist. (km)	Mag.	Max MMI(#)	Shaking Deaths
1993-12-20	324	6.2	VIII(547)	0
1991-05-21	244	6.6	IX(2k)	0
1977-08-27	368	7.0	VIII(1k)	2

Selected City Exposure

from GeoNames.org

MMI	City	Population
IV	**Dili**	**150k**
III	Larrakeyah	3k
III	Leanyer	5k
III	Nightcliff	3k
III	Parap	2k
III	Ludmilla	2k
III	Fannie Bay	2k
III	**Darwin**	**93k**
III	Stuart Park	3k
III	Palmerston	25k
III	McMinns Lagoon	5k

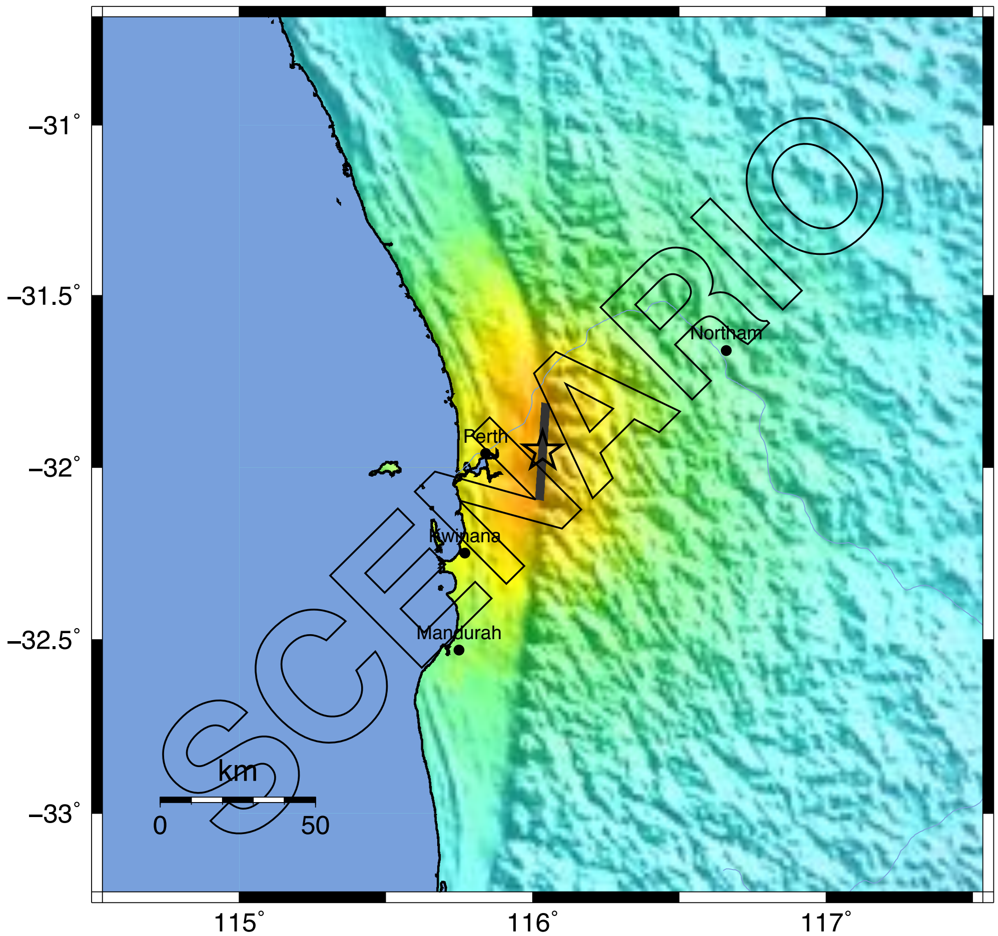
bold cities appear on map (k = x1000)

Event ID: usNorth_of_Australia_se

-- Earthquake Planning Scenario --

ShakeMap for Australia_SSPerth Scenario

Scenario Date: FEB 1 2012 12:00:00 AM GMT M 6.5 S31.95 E116.03 Depth: 5.3km



PLANNING SCENARIO ONLY -- Map Version 1 Processed Tue Sep 6, 2011 02:25:43 PM MDT

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<0.06	0.2	0.8	2.0	4.8	12	29	70	>171
PEAK VEL.(cm/s)	*<0.02*	*0.08*	*0.3*	*0.9*	*2.4*	*6.4*	*17*	*45*	*>120*
INSTRUMENTAL INTENSITY	I	II–III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Faenza and Michelini, 2010

Earthquake Shaking **Red Alert**

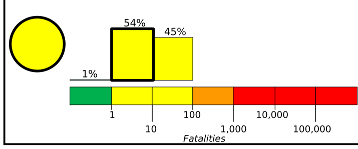
M 6.5, Strike slip event West of Perth

Origin Time: Wed 2012-02-01 00:00:00 UTC (08:00:00 local)
Location: 31.95°S 116.03°E Depth: 5 km

PAGER Version 1

Created: 20 minutes after earthquake

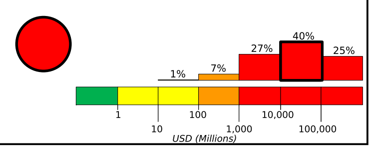
Estimated Fatalities



Red alert level for economic losses. Extensive damage is probable and the disaster is likely widespread. Estimated economic losses are 1-5% GDP of Australia. Past events with this alert level have required a national or international level response.

Yellow alert level for shaking-related fatalities. Some casualties are possible.

Estimated Economic Losses



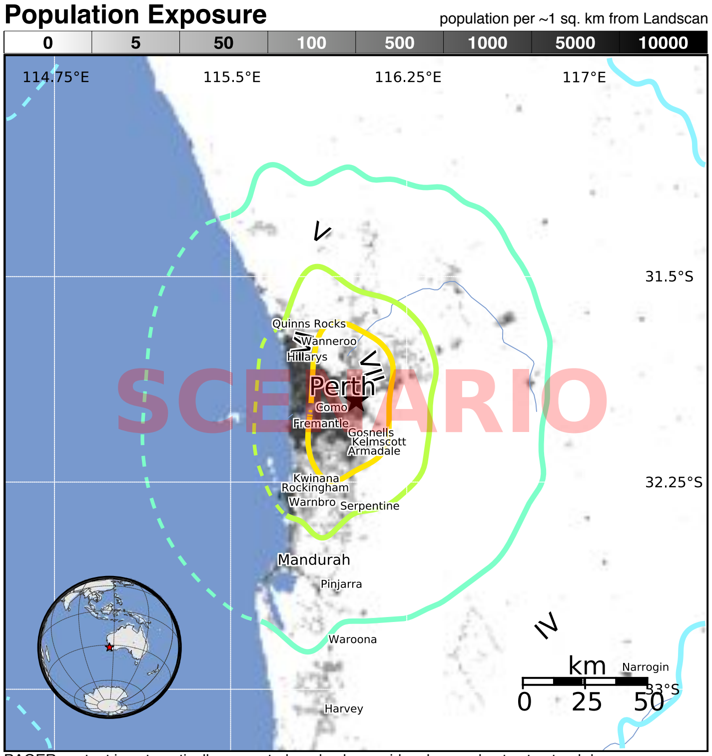
Estimated Population Exposed to Earthquake Shaking

ESTIMATED POPULATION EXPOSURE (k = x1000)		- -*	887*	37k*	129k	776k	581k	152k	0	0
ESTIMATED MODIFIED MERCALLI INTENSITY		I	II-III	IV	V	VI	VII	VIII	IX	X+
PERCEIVED SHAKING		Not felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	Resistant Structures	none	none	none	V. Light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy
	Vulnerable Structures	none	none	none	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy	V. Heavy

*Estimated exposure only includes population within the map area.

Population Exposure

population per ~1 sq. km from Landscan



PAGER content is automatically generated, and only considers losses due to structural damage.
Limitations of input data, shaking estimates, and loss models may add uncertainty.
http://earthquake.usgs.gov/pager

Structures:
Overall, the population in this region resides in structures that are resistant to earthquake shaking, though some vulnerable structures exist. The two model building types that contribute most to fatalities are unreinforced double brick cavity wall and reinforced concrete frame.

Historical Earthquakes (with MMI levels):

Date (UTC)	Dist. (km)	Mag.	Max MMI(#)	Shaking Deaths
1990-01-17	103	5.5	VI(265)	0
1979-06-02	162	6.1	VIII(36)	0

Selected City Exposure

from GeoNames.org

MMI	City	Population
VIII	Middle Swan	3k
VIII	Bellevue	2k
VIII	Midland	4k
VIII	Maddington	9k
VIII	Kenwick	5k
VIII	Guildford	2k
VIII	**Gosnells**	**17k**
VI	**Perth**	**1,447k**
VI	**Kwinana**	**20k**
VI	**Rockingham**	**13k**
V	**Mandurah**	**73k**

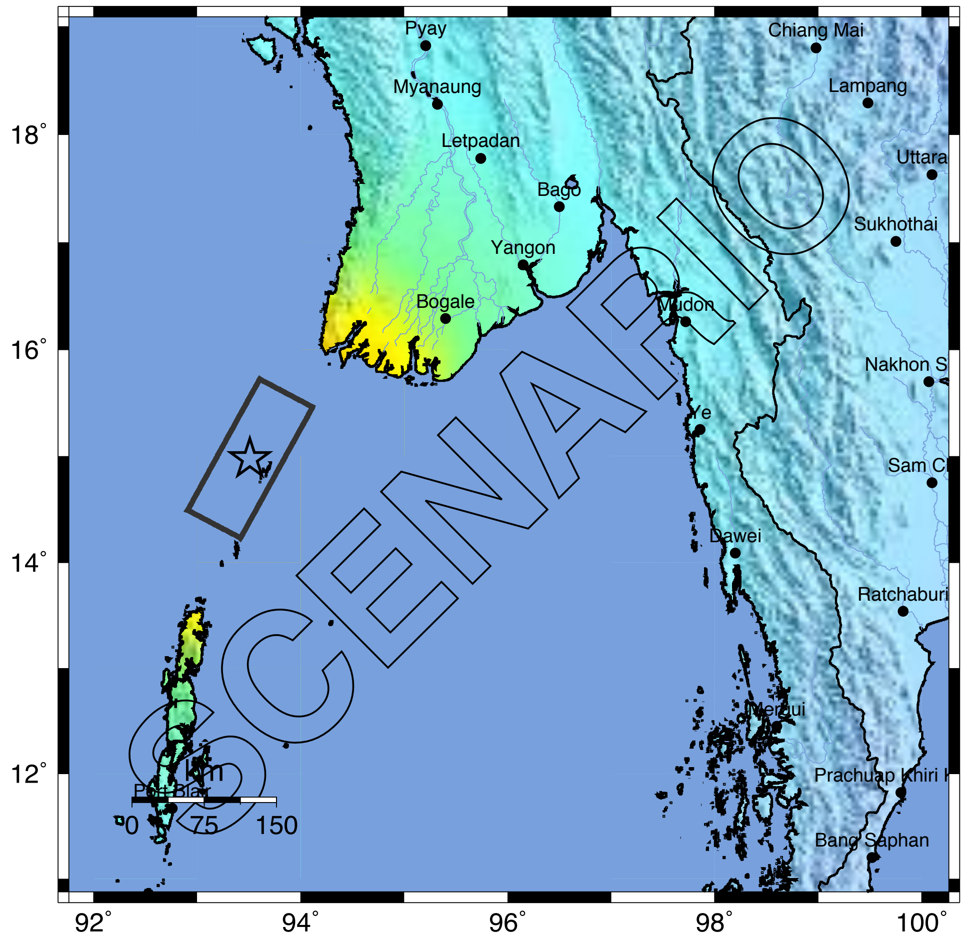
bold cities appear on map (k = x1000)

Event ID: usAustralia_SSPerth_se

-- Earthquake Planning Scenario --

ShakeMap for Thailand_Subduction Scenario

Scenario Date: FEB 1 2012 12:00:00 AM GMT M 8.0 N14.98 E93.51 Depth: 25.0km



PLANNING SCENARIO ONLY -- Map Version 1 Processed Tue Sep 27, 2011 01:05:39 PM MDT

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	***<0.1***	***0.5***	***2.4***	***6.7***	***13***	24	44	83	>156
PEAK VEL.(cm/s)	<0.07	0.4	1.9	5.8	***11***	***22***	***43***	***83***	***>160***
INSTRUMENTAL INTENSITY	I	II–III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Wald, et al.; 1999

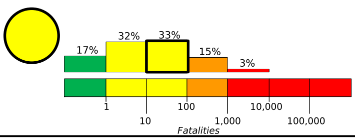
Earthquake Shaking **Yellow Alert**

M 8.0, Subduction event west of Thailand

Origin Time: Wed 2012-02-01 00:00:00 UTC (06:00:00 local)
Location: 14.98°N 93.51°E Depth: 25 km
FOR TSUNAMI INFORMATION, SEE: tsunami.noaa.gov

PAGER Version 1
Created: 20 minutes after earthquake

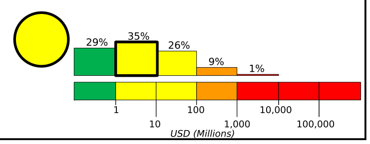
Estimated Fatalities



Yellow alert for shaking-related fatalities and economic losses. Some casualties and damage are possible and the impact should be relatively localized. Past yellow alerts have required a local or regional level response.

Estimated economic losses are less than 1% of GDP of Myanmar.

Estimated Economic Losses



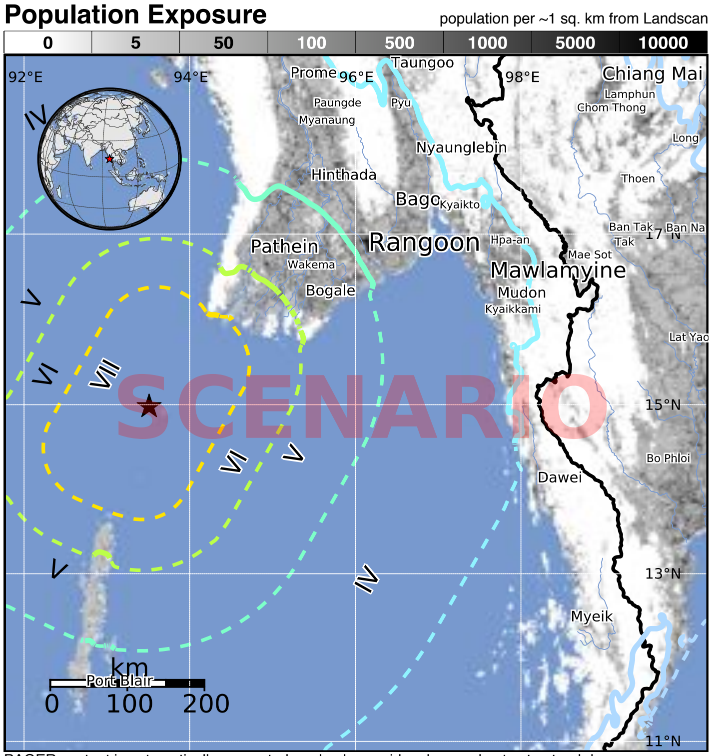
Estimated Population Exposed to Earthquake Shaking

ESTIMATED POPULATION EXPOSURE (k = x1000)		- -*	13,660k*	16,289k*	5,201k*	561k	37k	0	0	0
ESTIMATED MODIFIED MERCALLI INTENSITY		I	II-III	IV	V	VI	VII	VIII	IX	X+
PERCEIVED SHAKING		Not felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	Resistant Structures	none	none	none	V. Light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy
	Vulnerable Structures	none	none	none	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy	V. Heavy

*Estimated exposure only includes population within the map area.

Population Exposure

population per ~1 sq. km from Landscan



PAGER content is automatically generated, and only considers losses due to structural damage.
Limitations of input data, shaking estimates, and loss models may add uncertainty.
http://earthquake.usgs.gov/pager

Structures:
Overall, the population in this region resides in structures that are highly vulnerable to earthquake shaking, though some resistant structures exist. The two model building types that contribute most to fatalities are unreinforced masonry and reinforced concrete frame with masonry infill.

Historical Earthquakes (with MMI levels):

Date (UTC)	Dist. (km)	Mag.	Max MMI(#)	Shaking Deaths
1991-04-01	250	6.0	VII(10k)	0
1980-08-27	155	5.2	VII(21k)	0
1978-09-30	308	5.7	VIII(11k)	0

Recent earthquakes in this area have caused secondary hazards such as tsunamis that might have contributed to losses.

Selected City Exposure

from GeoNames.org

MMI	City	Population
V	**Pathein**	**237k**
V	Mawlamyinegyunn	39k
V	**Bogale**	**69k**
V	**Wakema**	**43k**
V	Pyapon	66k
V	Kyaiklat	52k
IV	**Rangoon**	**4,478k**
IV	**Bago**	**244k**
IV	**Mawlamyine**	**439k**
III	**Chiang Mai**	**201k**
III	Lampang	156k

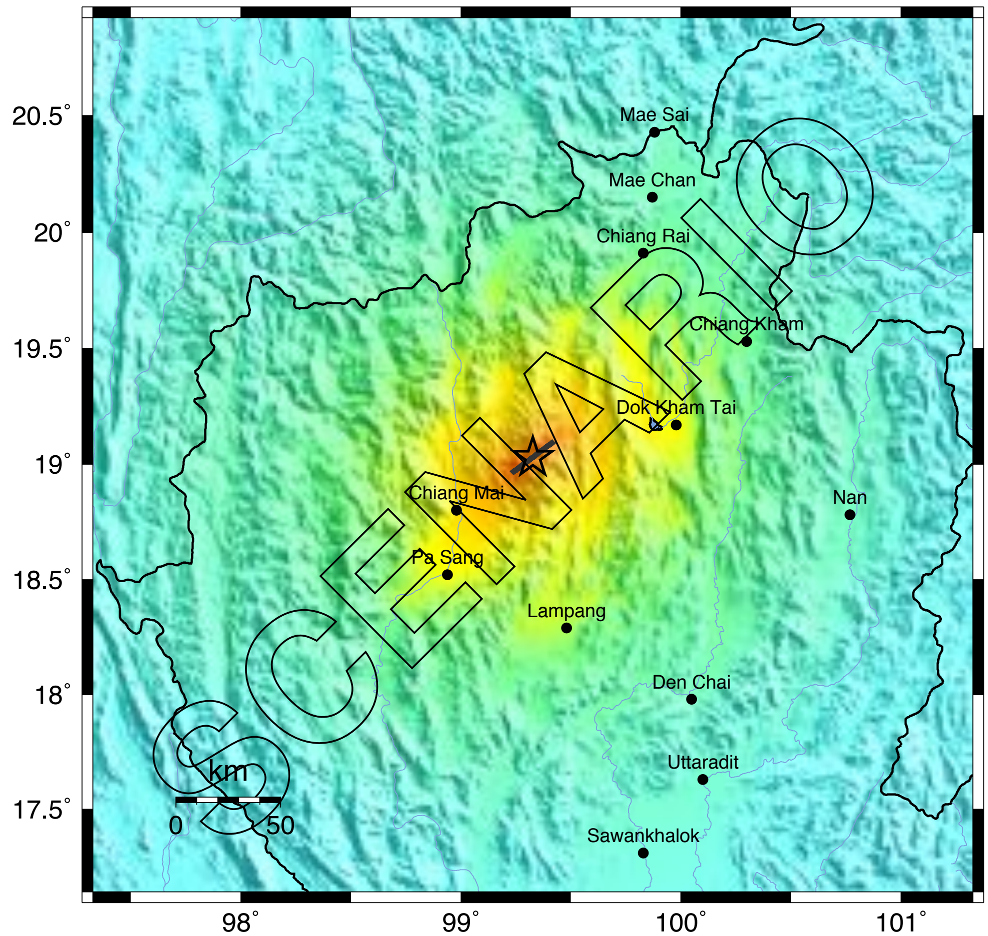
bold cities appear on map (k = x1000)

Event ID: usThailand_Subduction_se

-- Earthquake Planning Scenario --

ShakeMap for Thailand_Mae_Kuang Scenario

Scenario Date: FEB 1 2012 12:00:00 AM GMT M 6.5 N19.03 E99.33 Depth: 5.0km



PLANNING SCENARIO ONLY -- Map Version 1 Processed Tue Sep 6, 2011 02:23:35 PM MDT

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	*<0.1*	*0.5*	*2.4*	*6.7*	*13*	24	44	83	>156
PEAK VEL.(cm/s)	<0.07	0.4	1.9	5.8	*11*	*22*	*43*	*83*	*>160*
INSTRUMENTAL INTENSITY	I	II–III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Wald, et al.; 1999

Earthquake Shaking Yellow Alert

USGS science for a changing world · USAID FROM THE AMERICAN PEOPLE · GSN · ANSS

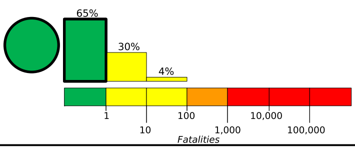
M 6.5, Surface event on Mae Kuang Fault, E. of Chiang Mai

PAGER Version 1

Origin Time: Wed 2012-02-01 00:00:00 UTC (07:00:00 local)
Location: 19.03°N 99.33°E Depth: 5 km

Created: 20 minutes after earthquake

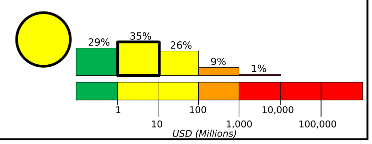
Estimated Fatalities



Yellow alert level for economic losses. Some damage is possible and the impact should be relatively localized. Estimated economic losses are less than 1% of GDP of Thailand. Past events with this alert level have required a local or regional level response.

Green alert level for shaking-related fatalities. There is a low likelihood of casualties.

Estimated Economic Losses



Estimated Population Exposed to Earthquake Shaking

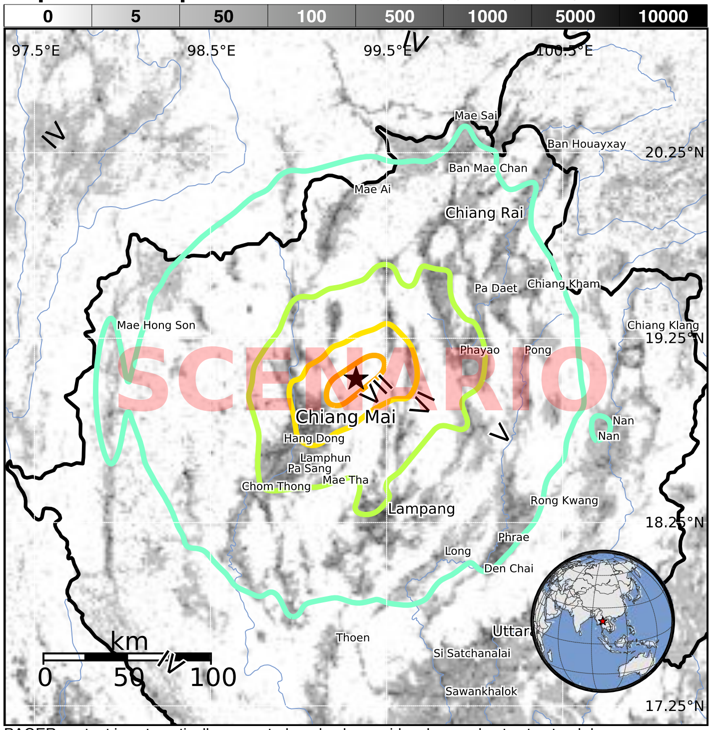
ESTIMATED POPULATION EXPOSURE (k = x1000)		- -*	- -*	3,132k*	3,055k	1,455k	782k	8k	12	0
ESTIMATED MODIFIED MERCALLI INTENSITY		I	II-III	IV	V	VI	VII	VIII	IX	X+
PERCEIVED SHAKING		Not felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	Resistant Structures	none	none	none	V. Light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy
	Vulnerable Structures	none	none	none	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy	V. Heavy

*Estimated exposure only includes population within the map area.

Population Exposure

population per ~1 sq. km from Landscan

0	5	50	100	500	1000	5000	10000



PAGER content is automatically generated, and only considers losses due to structural damage.
Limitations of input data, shaking estimates, and loss models may add uncertainty.
http://earthquake.usgs.gov/pager

Structures:
Overall, the population in this region resides in structures that are vulnerable to earthquake shaking, though some resistant structures exist. The two model building types that contribute most to fatalities are unreinforced masonry and reinforced concrete frame with masonry infill.

Historical Earthquakes (with MMI levels):

Date (UTC)	Dist. (km)	Mag.	Max MMI(#)	Shaking Deaths
1992-04-23	380	6.1	VIII(2k)	0
1992-04-23	379	6.1	VIII(4k)	4
1995-07-11	327	6.8	IX(3k)	11

Selected City Exposure

from GeoNames.org

MMI	City	Population
VII	San Kamphaeng	33k
VII	**Chiang Mai**	**201k**
VI	**Hang Dong**	**18k**
VI	San Pa Tong	18k
VI	**Phayao**	**21k**
VI	**Lamphun**	**< 1k**
V	**Lampang**	**156k**
V	**Chiang Rai**	**79k**
V	**Phrae**	**39k**
V	**Nan**	**25k**
IV	**Uttaradit**	**58k**

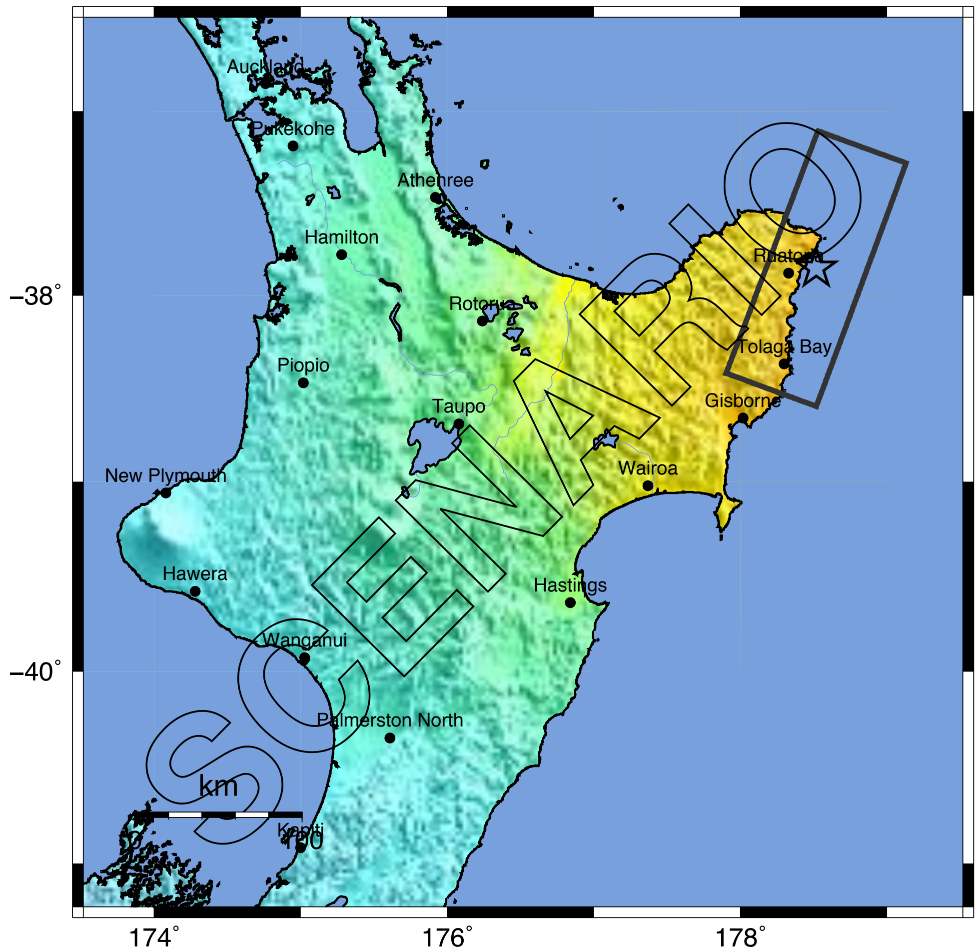
bold cities appear on map (k = x1000)

Event ID: usThailand_Mae_Kuang_se

-- Earthquake Planning Scenario --

ShakeMap for NewZealand_Subduction Scenario

Scenario Date: FEB 1 2012 12:00:00 AM GMT M 8.0 S37.85 E178.52 Depth: 25.1km



PLANNING SCENARIO ONLY -- Map Version 1 Processed Thu Sep 8, 2011 01:45:37 PM MDT

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<0.1	0.5	2.4	6.7	13	24	44	83	>156
PEAK VEL.(cm/s)	<0.07	0.4	1.9	5.8	11	22	43	83	>160
INSTRUMENTAL INTENSITY	I	II–III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Wald, et al.; 1999

science for a changing world

Earthquake Shaking | Orange Alert

M 8.0, Northern New Zealand subduction event

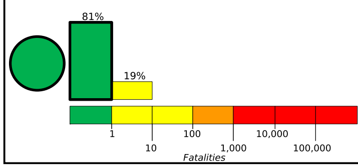
Origin Time: Wed 2012-02-01 00:00:00 UTC (12:00:00 local)
Location: 37.85°S 178.52°E Depth: 25 km

GSN ANSS USAID FROM THE AMERICAN PEOPLE

PAGER Version 1

Created: 20 minutes after earthquake

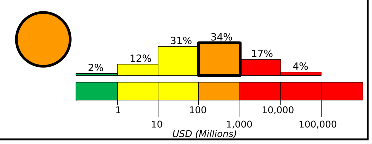
Estimated Fatalities



Orange alert level for economic losses. Significant damage is likely and the disaster is potentially widespread. Estimated economic losses are less than 1% of GDP of New Zealand. Past events with this alert level have required a regional or national level response.

Green alert level for shaking-related fatalities. There is a low likelihood of casualties.

Estimated Economic Losses



Estimated Population Exposed to Earthquake Shaking

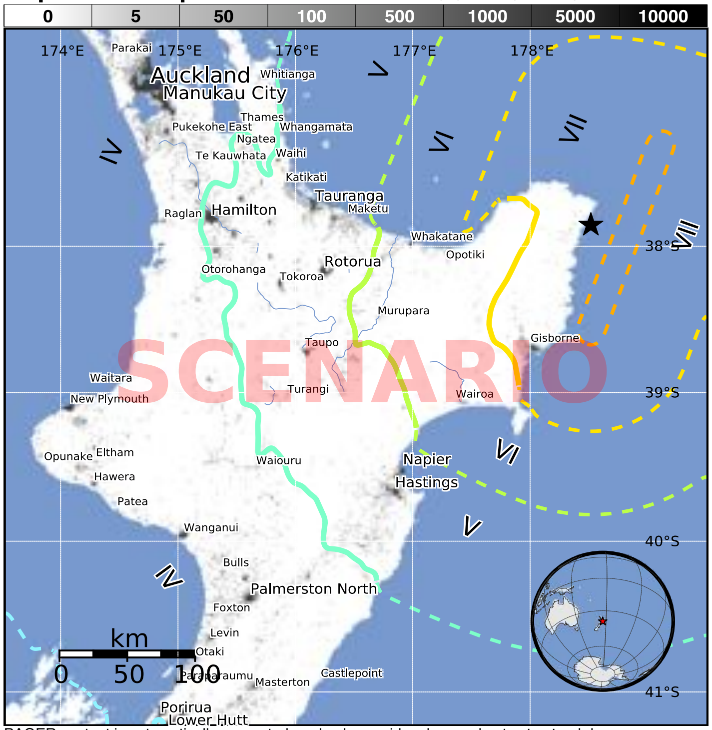
ESTIMATED POPULATION EXPOSURE (k = x1000)		- -*	43k*	2,029k*	690k*	58k*	50k*	47	0	0
ESTIMATED MODIFIED MERCALLI INTENSITY		I	II-III	IV	V	VI	VII	VIII	IX	X+
PERCEIVED SHAKING		Not felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	Resistant Structures	none	none	none	V. Light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy
	Vulnerable Structures	none	none	none	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy	V. Heavy

*Estimated exposure only includes population within the map area.

Population Exposure

population per ~1 sq. km from Landscan

0	5	50	100	500	1000	5000	10000



PAGER content is automatically generated, and only considers losses due to structural damage. Limitations of input data, shaking estimates, and loss models may add uncertainty.
http://earthquake.usgs.gov/pager

Structures:
Overall, the population in this region resides in structures that are resistant to earthquake shaking, though some vulnerable structures exist.

Historical Earthquakes (with MMI levels):

Date (UTC)	Dist. (km)	Mag.	Max MMI(#)	Shaking Deaths
1982-09-02	260	5.4	VII(47k)	0
1987-03-02	146	6.5	IX(389)	0
2004-07-18	184	5.4	VII(667)	1

Recent earthquakes in this area have caused secondary hazards such as landslides that might have contributed to losses.

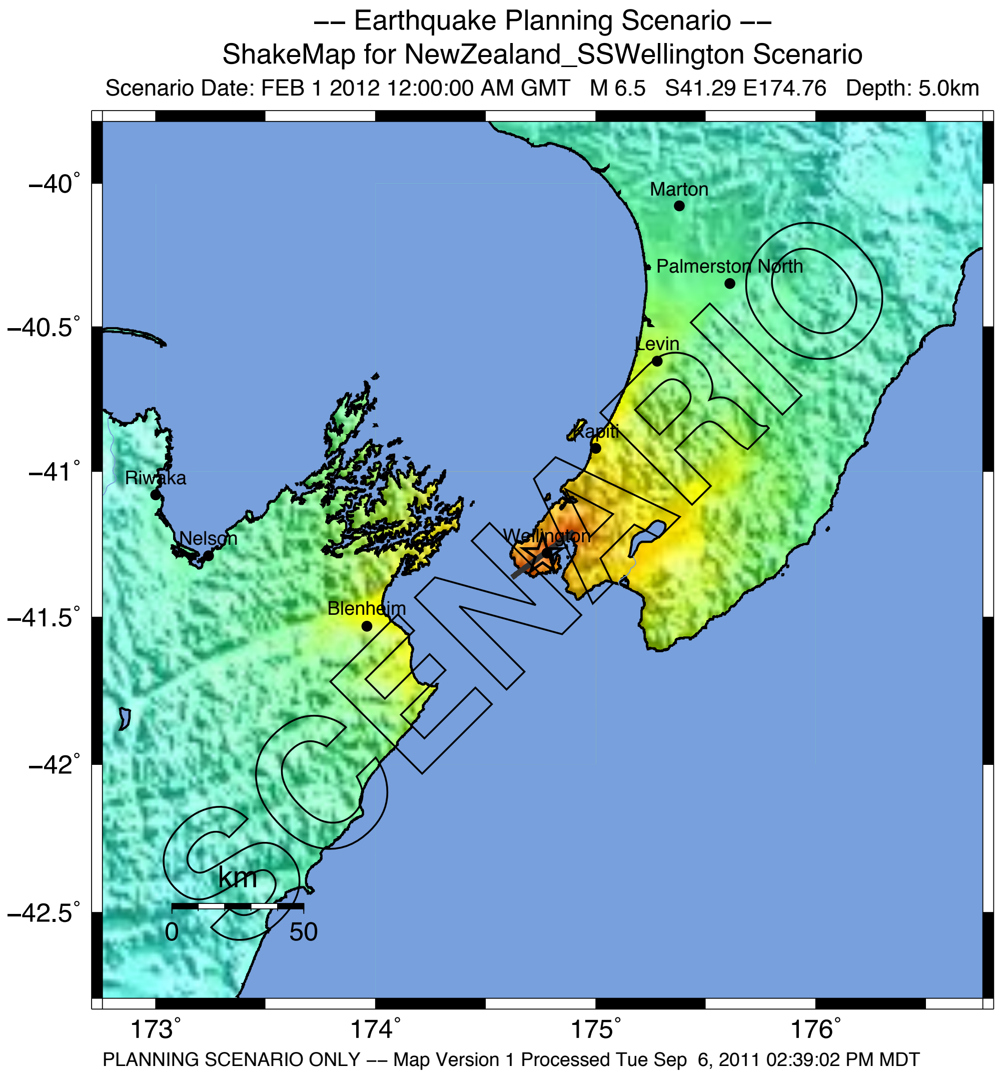
Selected City Exposure

from GeoNames.org

MMI	City	Population
VII	**Gisborne**	34k
VI	**Opotiki**	4k
VI	Edgecumbe	2k
VI	**Wairoa**	4k
VI	**Whakatane**	19k
VI	**Murupara**	2k
V	**Napier**	57k
V	**Hamilton**	153k
IV	**Manukau City**	362k
IV	**Auckland**	418k
IV	North Shore	208k

bold cities appear on map (k = x1000)

Event ID: usNewZealand_Subduction_se



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	*<0.1*	*0.5*	*2.4*	*6.7*	*13*	24	44	83	>156
PEAK VEL.(cm/s)	<0.07	0.4	1.9	5.8	*11*	*22*	*43*	*83*	*>160*
INSTRUMENTAL INTENSITY	I	II–III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Wald, et al.; 1999

USGS
science for a changing world

Earthquake Shaking **Red Alert**

USAID FROM THE AMERICAN PEOPLE
GSN ANSS

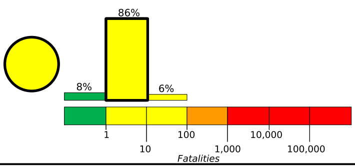
M 6.5, Wellington fault strike slip event

Origin Time: Wed 2012-02-01 00:00:00 UTC (12:00:00 local)
Location: 41.29°S 174.76°E Depth: 5 km

PAGER Version 1

Created: 20 minutes after earthquake

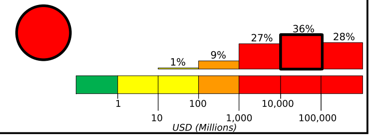
Estimated Fatalities



Red alert level for economic losses. Extensive damage is probable and the disaster is likely widespread. Estimated economic losses are 8-40% GDP of New Zealand. Past events with this alert level have required a national or international level response.

Yellow alert level for shaking-related fatalities. Some casualties are possible.

Estimated Economic Losses



Estimated Population Exposed to Earthquake Shaking

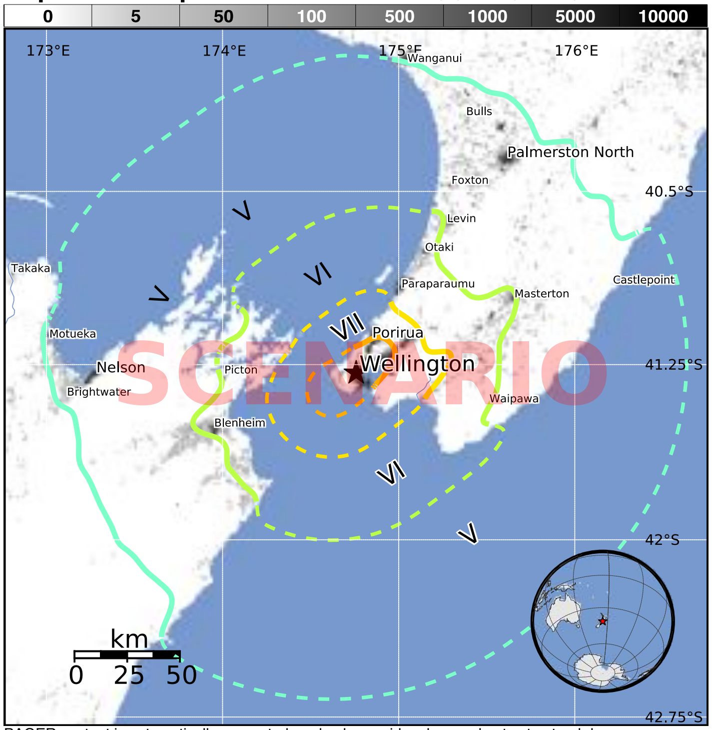
ESTIMATED POPULATION EXPOSURE (k = x1000)		- -*	- -*	72k*	269k	104k	90k	289k	26k	0
ESTIMATED MODIFIED MERCALLI INTENSITY		I	II-III	IV	V	VI	VII	VIII	IX	X+
PERCEIVED SHAKING		Not felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	Resistant Structures	none	none	none	V. Light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy
	Vulnerable Structures	none	none	none	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy	V. Heavy

*Estimated exposure only includes population within the map area.

Population Exposure

population per ~1 sq. km from Landscan

0	5	50	100	500	1000	5000	10000



PAGER content is automatically generated, and only considers losses due to structural damage.
Limitations of input data, shaking estimates, and loss models may add uncertainty.
http://earthquake.usgs.gov/pager

Structures:
Overall, the population in this region resides in structures that are resistant to earthquake shaking, though some vulnerable structures exist. The two model building types that contribute most to fatalities are unreinforced masonry and nonductile reinforced concrete frame.

Historical Earthquakes (with MMI levels):

Date (UTC)	Dist. (km)	Mag.	Max MMI(#)	Shaking Deaths
1990-02-10	196	6.0	VIII(61)	0
1990-05-13	161	6.4	VIII(440)	0
2004-07-18	391	5.4	VII(667)	1

Recent earthquakes in this area have caused secondary hazards such as landslides that might have contributed to losses.

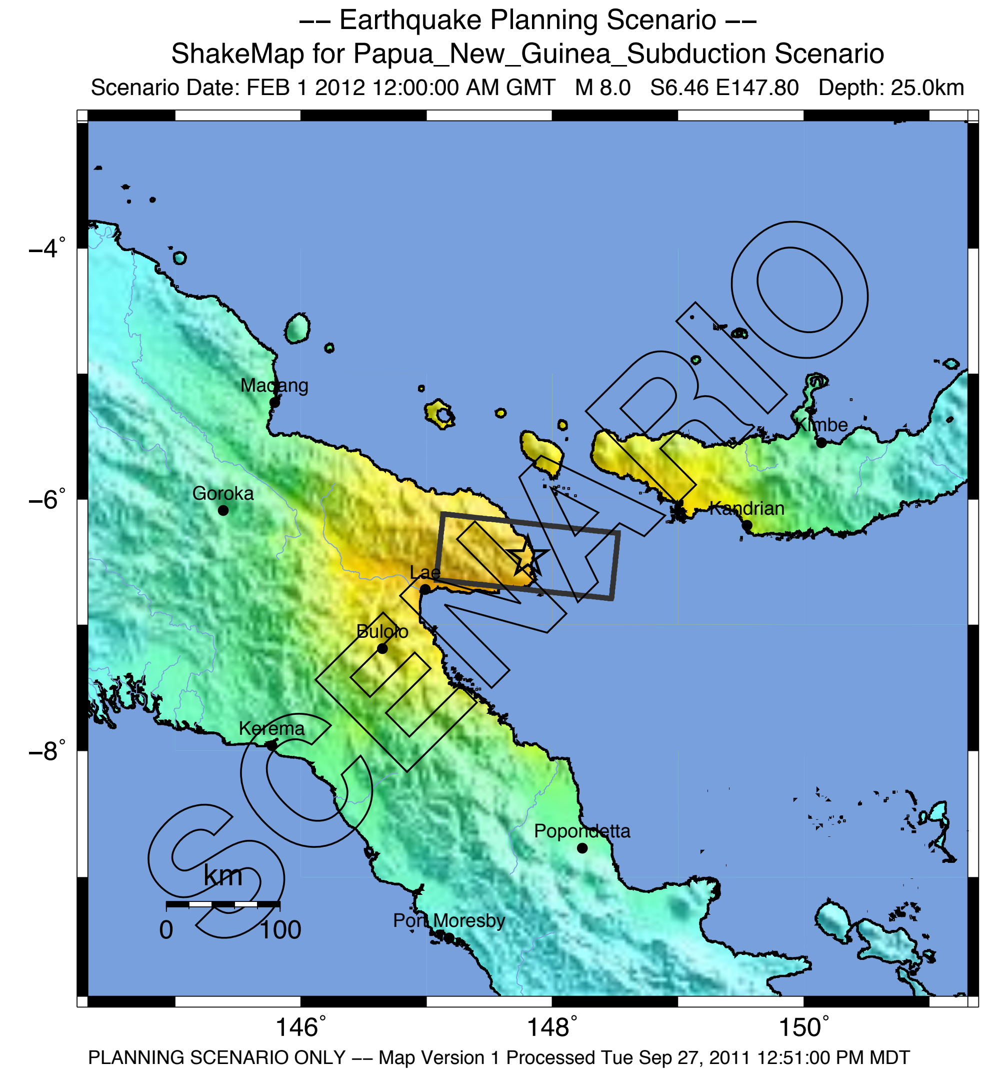
Selected City Exposure

from GeoNames.org

MMI	City	Population
IX	**Wellington**	**382k**
VIII	Lower Hutt	101k
VIII	**Porirua**	**51k**
VII	Upper Hutt	38k
VI	**Otaki**	**6k**
VI	**Paraparaumu**	**25k**
VI	**Blenheim**	**27k**
VI	**Masterton**	**21k**
V	**Palmerston North**	**76k**
V	**Nelson**	**59k**
IV	**Wanganui**	**40k**

bold cities appear on map (k = x1000)

Event ID: usNewZealand_SSWellington_se



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<0.1	0.5	2.4	6.7	13	24	44	83	>156
PEAK VEL.(cm/s)	<0.07	0.4	1.9	5.8	11	22	43	83	>160
INSTRUMENTAL INTENSITY	I	II–III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Wald, et al.; 1999

USGS
science for a changing world

Earthquake Shaking — Yellow Alert

GSN ANSS USAID FROM THE AMERICAN PEOPLE

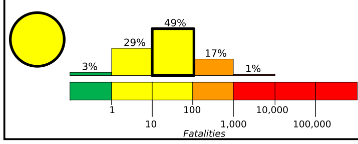
M 8.0, East coast of Papua New Guinea

Origin Time: Wed 2012-02-01 00:00:00 UTC (10:00:00 local)
Location: 6.46°S 147.80°E Depth: 25 km

PAGER Version 1

Created: 20 minutes after earthquake

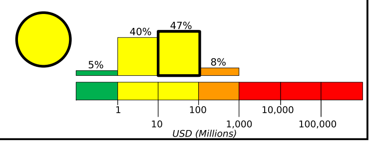
Estimated Fatalities



Yellow alert for shaking-related fatalities and economic losses. Some casualties and damage are possible and the impact should be relatively localized. Past yellow alerts have required a local or regional level response.

Estimated economic losses are less than 1% of GDP of Papua New Guinea.

Estimated Economic Losses



Estimated Population Exposed to Earthquake Shaking

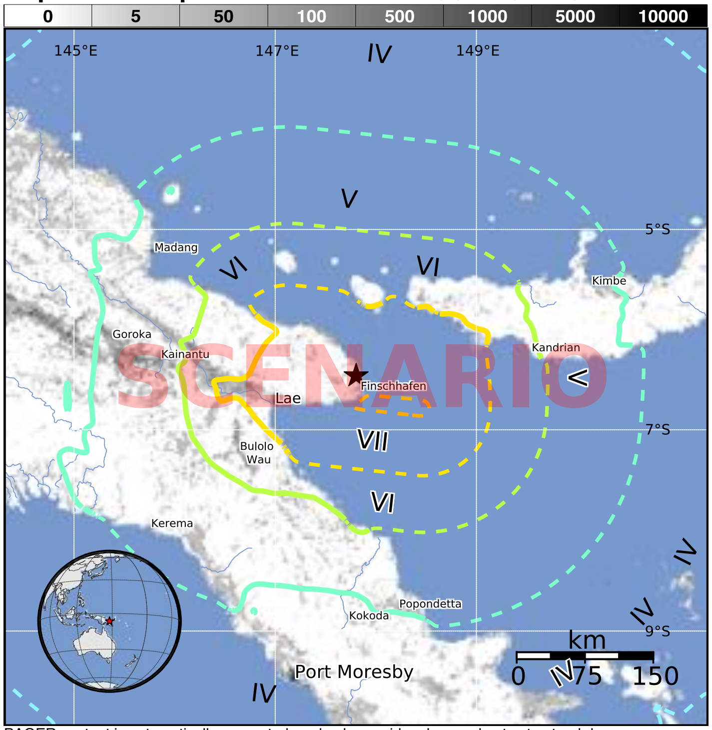
ESTIMATED POPULATION EXPOSURE (k = x1000)		- -*	7k*	1,472k*	1,104k	352k	301k	61k	0	0
ESTIMATED MODIFIED MERCALLI INTENSITY		I	II-III	IV	V	VI	VII	VIII	IX	X+
PERCEIVED SHAKING		Not felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	Resistant Structures	none	none	none	V. Light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy
	Vulnerable Structures	none	none	none	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy	V. Heavy

*Estimated exposure only includes population within the map area.

Population Exposure

population per ~1 sq. km from Landscan

0	5	50	100	500	1000	5000	10000



PAGER content is automatically generated, and only considers losses due to structural damage. Limitations of input data, shaking estimates, and loss models may add uncertainty.

http://earthquake.usgs.gov/pager

Structures:
Overall, the population in this region resides in structures that are vulnerable to earthquake shaking, though some resistant structures exist. The two model building types that contribute most to fatalities are traditional Bamboo/Bush houses and unreinforced masonry.

Historical Earthquakes (with MMI levels):

Date (UTC)	Dist. (km)	Mag.	Max MMI(#)	Shaking Deaths
1993-10-13	197	6.9	VIII(30k)	0
1985-05-10	372	7.2	VII(28k)	1
1993-10-16	180	6.3	VII(75k)	3

Recent earthquakes in this area have caused secondary hazards such as tsunamis, landslides, and liquefaction that might have contributed to losses.

Selected City Exposure

from GeoNames.org

MMI	City	Population
VII	Lae	76k
VII	Finschhafen	1k
VI	Bulolo	16k
VI	Wau	15k
VI	Kandrian	1k
V	Kainantu	9k
V	Madang	27k
V	Kimbe	19k
V	Goroka	19k
V	Popondetta	28k
IV	Port Moresby	284k

bold cities appear on map (k = x1000)

Event ID: usPapua_New_Guinea_Subduction_se

Surviving a Tsunami: Lessons Learned from the 2011 Tohoku Earthquake/Tsunami

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koshimura@tsunami2.civil.tohoku.ac.jp

Introduction

On 11 March, 2011 a devastating tsunami accompanied by a M9.0 earthquake struck the northern Pacific coast of Japan, and completely destroyed many coastal communities, particularly in the Iwate, Miyagi, and Fukushima prefectures. The total area affected by the tsunami was estimated as 561 km^2 along the Pacific coast of Japan (Geospatial Information Authority of Japan, 2011). The tsunami run-up height reached 40 m (The 2011 Tohoku Earthquake Tsunami Joint Survey Group, 2011).

As of 10 September, six months after the event, Japan's National Police Agency reported 15,781 dead (4656 in Iwate, 9456 in Miyagi, 1603 in Fukushima and 66 in other prefectures) and 4086 still missing. 115,151 buildings and/or houses collapsed or were washed away by the tsunami. The economic impacts have been estimated at 16 - 25 trillion yen (Cabinet Office, 24 June, 2011), compared to a FY2010 national budget of 92 trillion yen (Ministry of Finance, February, 2010).

Having passed six months since the event, the devastated areas have started moving forward to recover and reconstruct, or, in other words, renovate their communities. Approximately 82,000 residents who lost houses have moved from shelters to temporary houses (52,000 units were supplied) and rental housing (Ministry of Land, Infrastructure, Transport and Tourism, 2011). Eight-nine percent of an estimated 23 million tons of tsunami debris has been removed (Ministry of Environment, 2011). Though the recovery process continues, local governments have completed draft reconstruction plans that include infrastructure design, transportation, land use management, urban design, relocation, economic and industrial outlooks.

This paper will report on efforts to identify the impact of the 2011 Tohoku tsunami disaster and the lessons learned from this event, in the hopes of promoting the safety of schools and children within tsunami-resilient coastal communities.

Causes of Tsunami Generation

Tsunami is a Japanese term derived from the characters *tsu* (meaning harbor) and *nami* (meaning wave). The term is now widely known. A tsunami is defined as a series of water waves caused by the sudden displacement of a large volume of water, usually in an ocean or in large lakes. Due to the tremendous volumes of water released at high energy from its source, a tsunami can devastate coastal regions. Earthquakes, underwater explosions such as volcanic eruptions, landslides, underwater landslides and large mass movements (meteorite ocean impacts or similar impact events) all have the potential to generate a tsunami. For example, the 1883 Krakatau volcanic eruption generated a devastating tsunami that reached 38 m above sea level, killing thousands of people and destroying coastal villages.

Earthquakes that occur in a subduction zone, the area where an oceanic plate is subducting beneath an overriding plate, generate most tsunamis. The friction between the subducting plate and the overriding plate causes stress to build between plates. Usually, stress accumulates in the interface between plates (inter plate) over a long period of time, such as decades or centuries. Finally the stress accumulated between the plates reaches its limit and is suddenly released, as a fault rupture. This sudden motion occurring in shallow crust within ocean depths becomes the cause of the tsunami, because the sea floor deformation--such as uplift and subsidence--pushes up or draws down the overlying water, causing a sudden displacement of a large volume of water body (Figure 1).

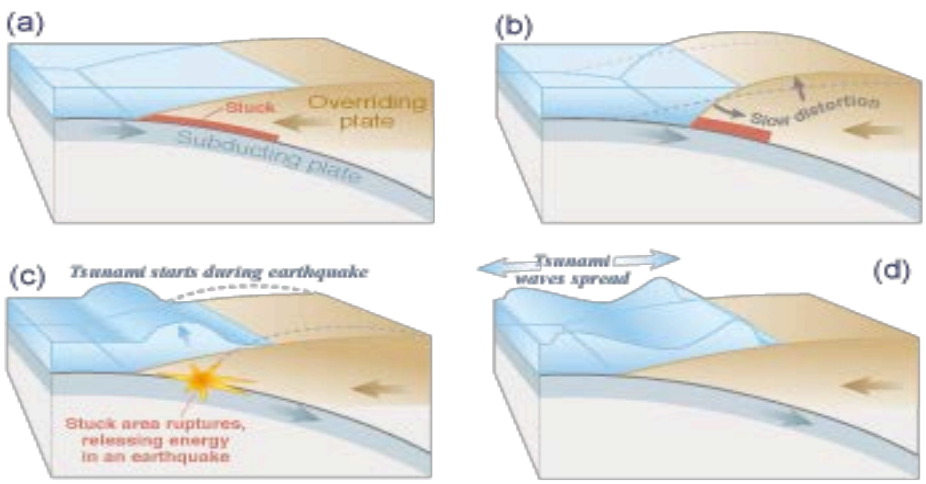

FIGURE 1 --- THE PROCESS OF STRESS ACCUMULATION BETWEEN THE PLATES AND GENERATION MECHANISM OF TSUNAMI (ATWATER ET AL., 1999). (A) SUBDUCTION OF OCEANIC PLATE UNDERNEATH CONTINENTAL PLATE, (B) ACCUMULATION OF STRESS BETWEEN THE PLATES, (C) ENERGY RELEASE BY FAULT RUPTURE TO CAUSE SEA BOTTOM DEFORMATION AND TSUNAMI GENERATION, (D) TSUNAMI PROPAGATION AND COASTAL INUNDATION.

Mechanisms of the 2011 Earthquake off the Pacific Coast of Tohoku

The March 11 Tohoku earthquake was caused by thrust faulting on the plate boundary between the Pacific and North American plates. There, the Pacific plate moves westwards at a speed of 8.5 cm/year and is subducting beneath the North American plate at the Japan Trench. Earthquake source studies imply that the fault rupture occurred with a slip amount of 30 m, over an area approximately 450 km by 150 km (Figure 2).

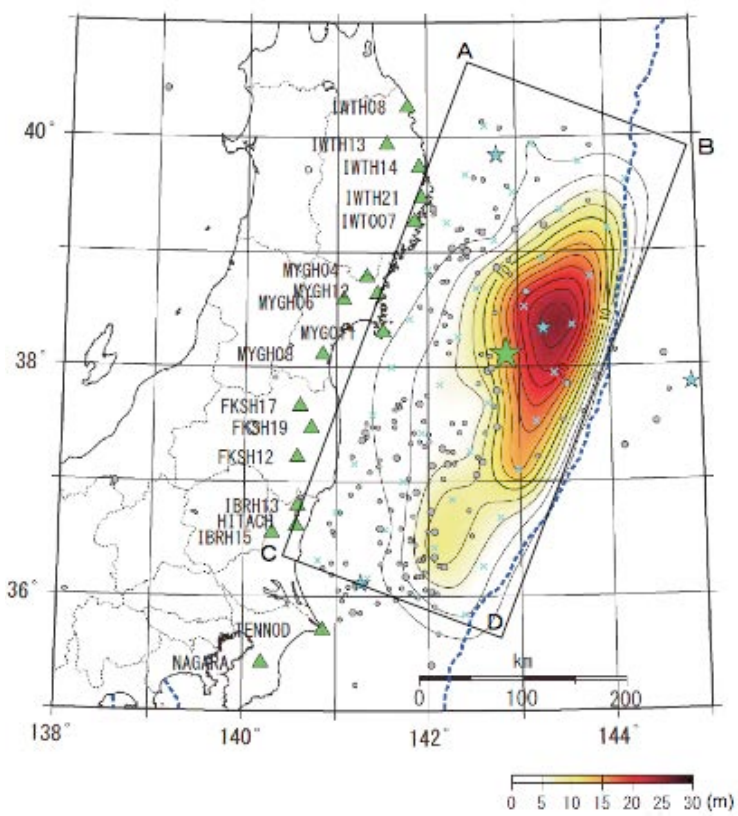

FIGURE 2. RUPTURE OF THE 2011 EARTHQUAKE OFF THE PACIFIC COAST OF TOHOKU (METEOROLOGICAL RESEARCH INSTITUTE, 2011).

Since 1973, nine earthquakes M7 or greater have occurred in the Japan Trench subduction zone (USGS, 2011). The largest one was M 7.8 (the 1994 offshore Sanriku earthquake) and occurred approximately 260 km north of the March 11 earthquake's epicenter. The Sanriku earthquake caused three fatalities and more than 700 injuries. In June 1978, a M 7.7 earthquake 35 km southwest of the March 11 epicenter caused 28 fatalities. Large offshore earthquakes occurred in the same subduction zone in 1611 (Keicho era), 1896 (Meiji era) and 1933 (Showa era), generating devastating tsunamis on the Pacific northeast coast of Japan (Sanriku).

The Sanriku coastline is particularly vulnerable to tsunamis, because it has many V-shaped bays that cause tsunami energy to converge and amplify. For example, the 1896 Meiji earthquake (M7.6) generated a tsunami as high as 38 m, which resulted in a reported death toll of 22,000. The 1933 Showa earthquake (M 8.6) tsunami reached as high as 29 m on the Sanriku coast and caused more than 3000 fatalities. Few earthquakes larger then M 8.0 have occurred along the northern part of the Japan trench and Kuril trench (off north Miyagi to Hokkaido), excepting the 869 (Jogan) and 1611 (Keicho) earthquakes.

The 2011 Tohoku Tsunami

To describe the overland flow of a tsunami, we define quantities as shown in Figure 3. Important quantities include the tsunami flow depth, tsunami inundation height, the run-up height and the inundation distance. Run-up height is the maximum ground elevation inundated by the tsunami on land. Flow depth is the depth of the tsunami flood over the local ground height, while the inundation height is the total elevation of the water free surface (water mark) above a reference datum, which is usually defined as the tide level under normal conditions.

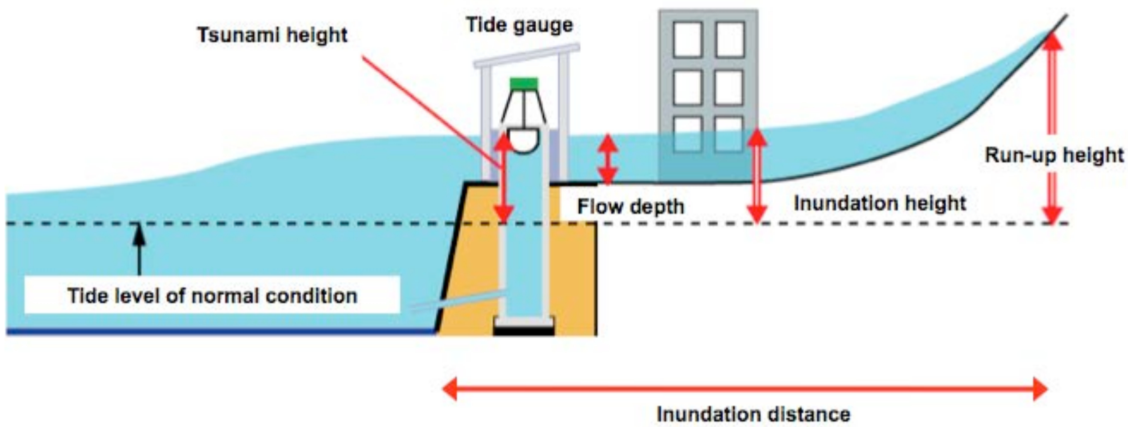

FIGURE 3 DEFINITION OF TSUNAMI HEIGHT (AFTER JAPAN METEOROLOGICAL AGENCY).

Figure 4 (following page) illustrates the measured tsunami inundation and run-up heights (2011 Tohoku Earthquake Tsunami Joint Survey Group, 2011), with plots of historical tsunami heights included (1611 Keicho Sanriku, 1896 Meiji Sanriku, and 1933 Showa Sanriku earthquake tsunamis). Northeast of Tohoku, the maximum run-up height in this event was similar to the events of both 1896 and 1933, especially of the 1896 Meiji Sanriku tsunami. However, the affected area of this event was much more extensive than in those historical events. In this sense, the 11 March 2011 event was the largest known tsunami event in Japan. In addition, a significant feature of the 2011 tsunami was the wide extent of the inundation zone; for example, on the Sendai plain, the tsunami inundated more than 5 km inland, causing devastating damage to populated areas and rice fields (Figure 5).

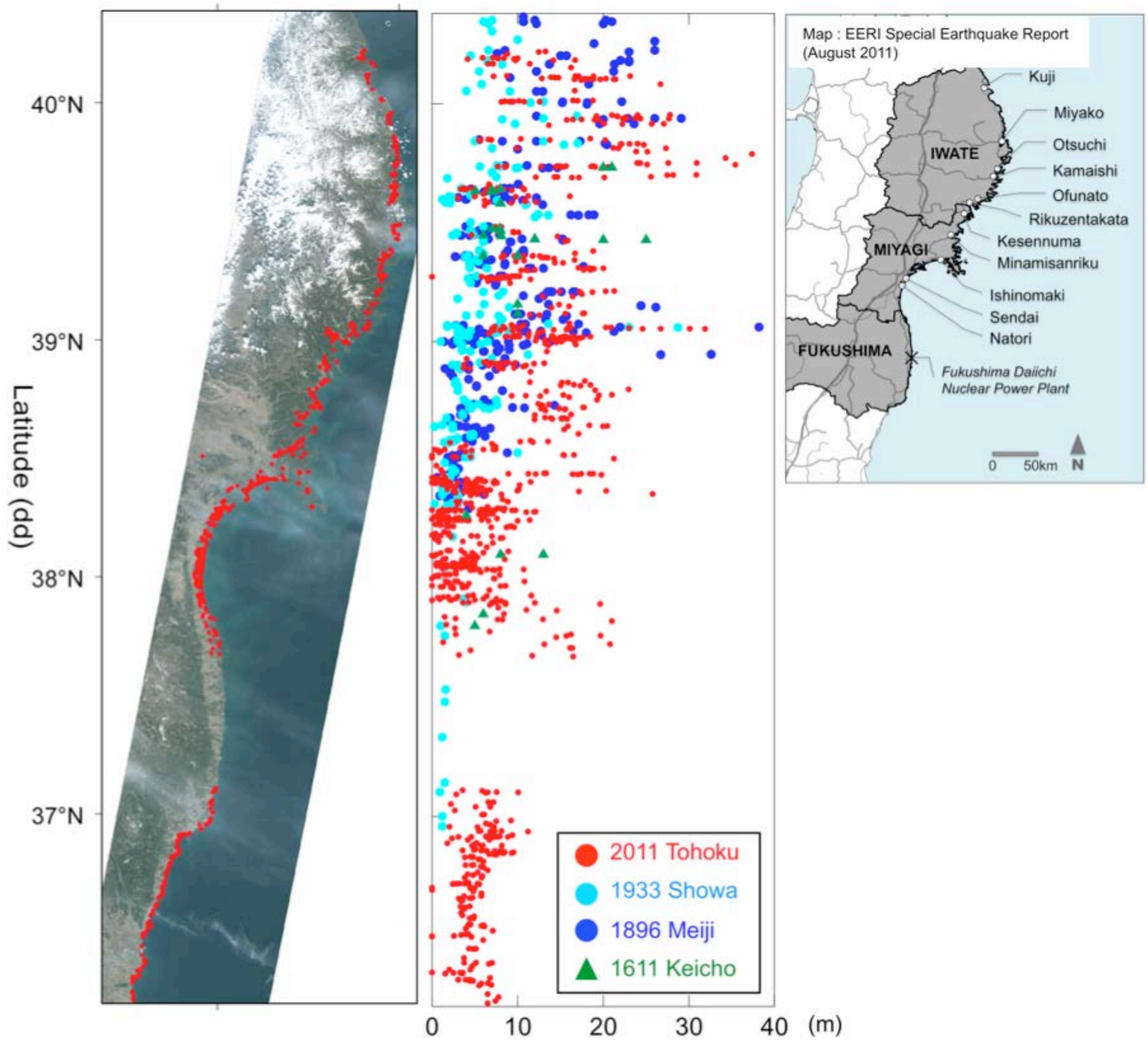

FIGURE 4 THE MEASURED HEIGHTS OF THE 2011 TOHOKU TSUNAMI AND HISTORICAL SANRIKU EARTHQUAKE TSUNAMIS (1611, 1896 AND 1933 EVENTS).

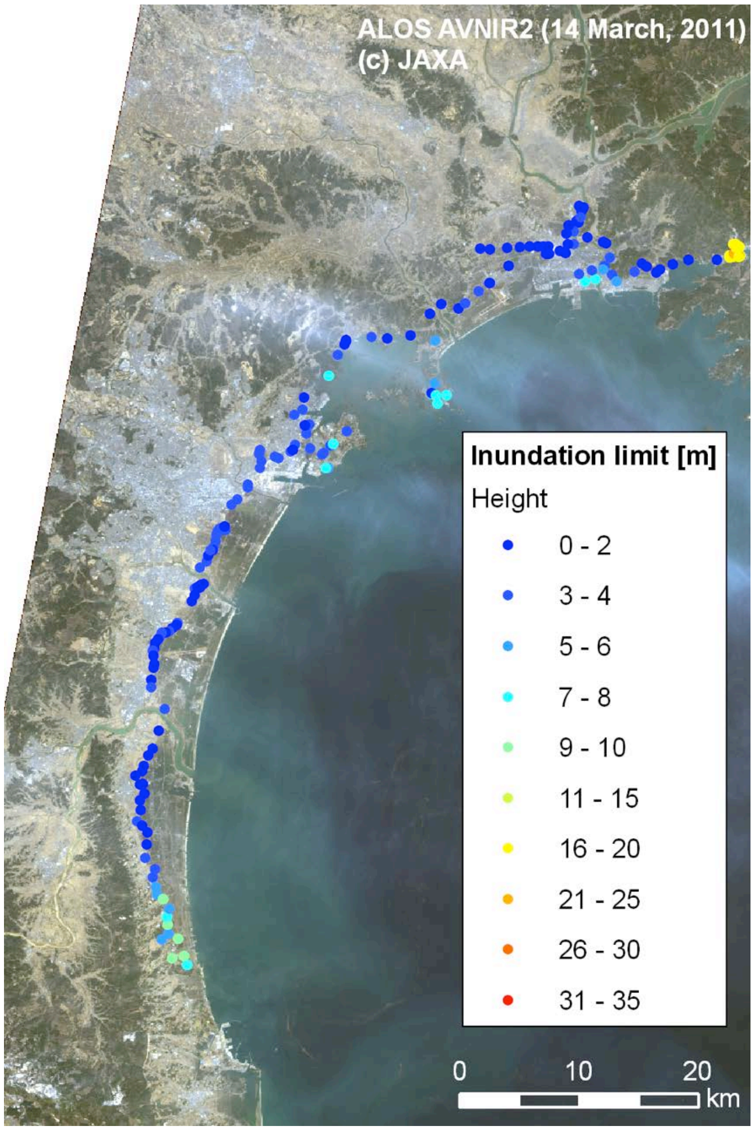

FIGURE 5 INLAND LIMIT OF TSUNAMI PENETRATION ON SENDAI PLAIN, MIYAGI PREFECTURE. THE COLORED DOTS REPRESENT THE POSITION AND THE GROUND HEIGHT OF THE INLAND LIMIT OF TSUNAMI INUNDATION.

Tsunami Propagation and Coastal Inundation

A tsunami is categorized as a "long wave" in water surface waves, which has much longer wavelength (*L*) than the water depth (*h*). When *h*/*L* of a water surface wave (train) is smaller than 1/20—in other words, when a wavelength is 20 times longer than the water depth (often hundreds of kilometers long, whereas normal ocean waves have a wavelength of only 30 or 40 meters), it has the characteristics of a long wave. Consider the moment that a tsunami is generated offshore at depths of several thousand meters by a sudden sea bottom deformation. Assuming the wavelength of a tsunami as a hundred kilometers and the initial height of the sea surface as several meters or even 10 meters, the horizontal scale of that tsunami is much larger than the vertical scale of sea surface movement. In this sense, tsunamis generally travel unnoticed in the deep sea, and ships are hardly aware of the wave's passage.

Simply, how fast a tsunami travels in the ocean can be described by the following formula

$$c = \sqrt{gh}$$

where *c* (m/s) is the speed of the tsunami (travel speed of long wave), *g* is the gravitational acceleration (=9.8 m/s^2), and *h* is the local water depth (m). Thus, the speed of tsunami propagation only depends on the water depth; a tsunami travels faster in the deeper ocean and slower in shallower seawaters. When we assume *h*=4000 m as an approximate average water depth in the Pacific Ocean, *c* is calculated as 198 m/s=713 km/h. This is almost the same order of speed as the cruising speed of a jet plane. However, when a tsunami propagates near shore area or in a bay entrance (e.g. *h*=30 m, *c* is as 17 m/s=61 km/h), its traveling speed is equivalent to the speed of a car. Finally, when a 5 m tsunami reaches a coast, *c* is reduced to 7 m/s=25 km/h, comparable to the speed of a small motorcycle. (Considering that a 5 m tsunami travels as fast as a motorcycle, going to a harbor or beach to watch a tsunami is suicide!)

As the tsunami approaches the coast and the water depth becomes shallower, reducing the tsunami's traveling speed, wave shoaling (the effect by which surface waves entering shallower water increase in wave height) compresses the tsunami, and its amplitude increases significantly (Figure 6). When fishermen who had not noticed a tsunami's passage, while they were at sea fishing, came back to shore, they could find their harbor and village devastated by a huge wave. This is why tsunami means "harbor wave."

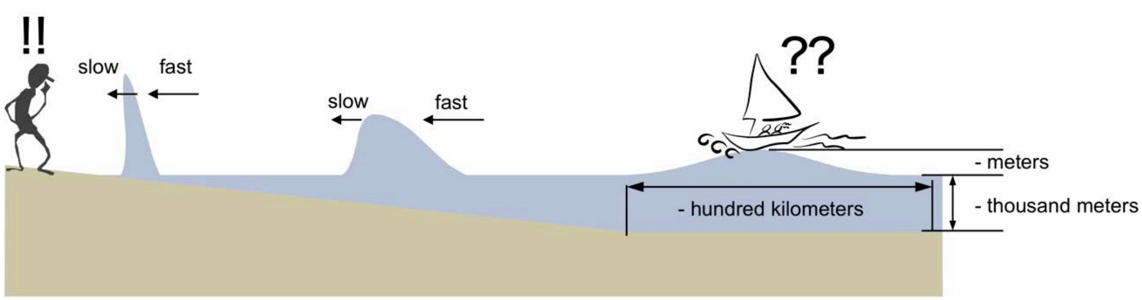

FIGURE 6. SCHEMATIC EXPLANATION OF TSUNAMI WAVE SHOALING.

Tsunamis Have No Border

The tsunami threat is not contained to the coast facing the fault rupture area. Sometimes a tsunami travels across the ocean as a so-called “tele-tsunami” or far field tsunami. A tele-tsunami is defined as a tsunami from its source more than 1000 km away from area of interest.

In 1960, a gigantic earthquake of M 9.5 occurred off the coast of south-central Chile and generated a tsunami that was devastating to the entire Pacific. The tsunami propagated across the Pacific Ocean, striking the Hawaiian islands with 10.5 m tsunami height, causing 61 fatalities and US$24 million in economic losses (National Geophysical Data Center), and then reaching all the way to Japan as an over 6 m tsunami, where it killed 142 people (Figure 7).

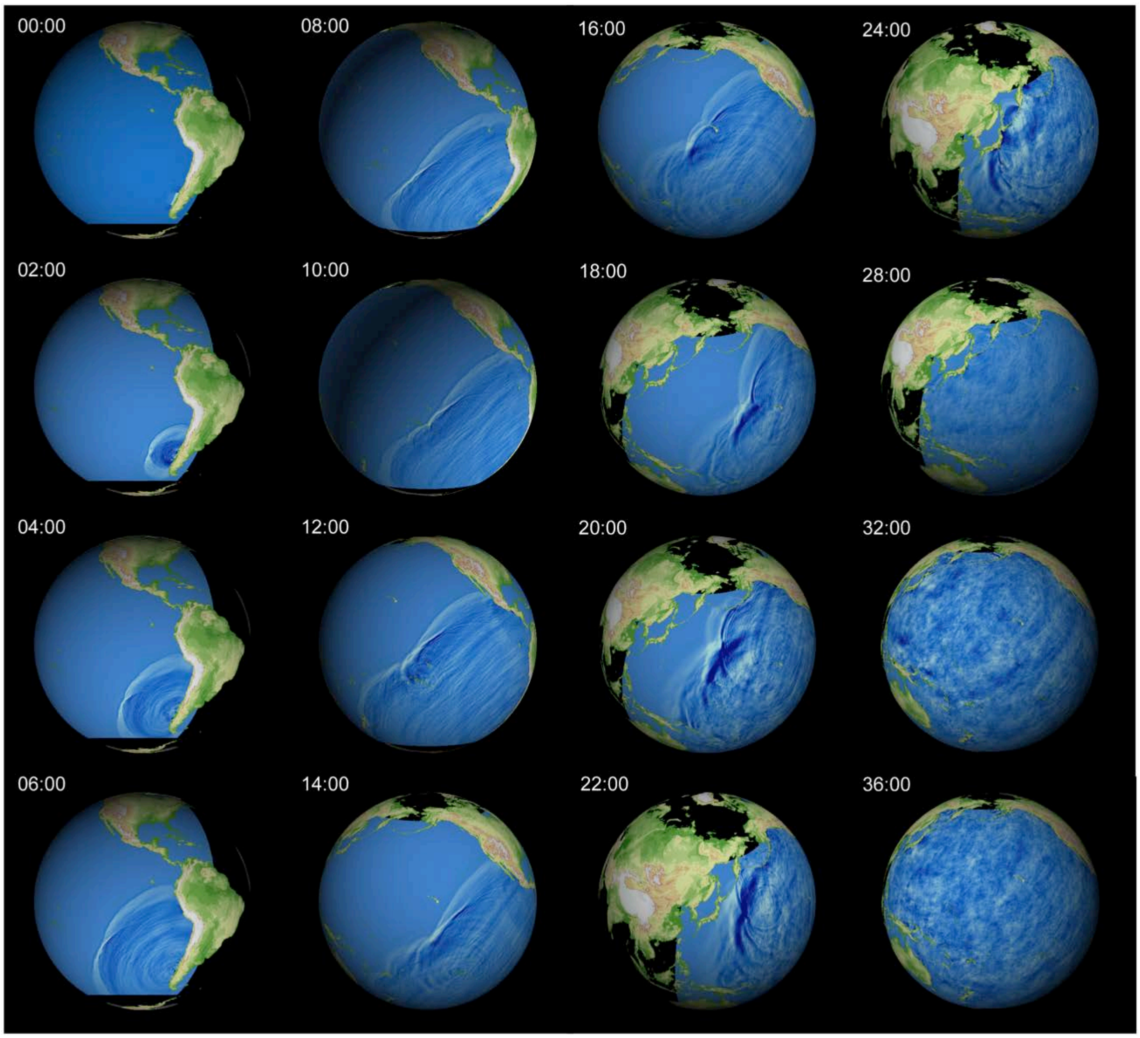

FIGURE 7 THE 1960 CHILEAN TSUNAMI SIMULATION TRAVELING ACROSS THE PACIFIC, WHERE IT WOULD CAUSE SEVERE DAMAGE TO THE HAWAIIAN ISLANDS AND JAPAN.

In recent years, the 2004 Sumatra-Andaman earthquake tsunami (known as the Indian Ocean Tsunami) and the 2010 Chilean earthquake tsunami affected many countries. Similarly, the 2011 Tohoku tsunami traveled across the Pacific, sank several boats in harbors along the coasts of Oregon and California (two states in the western United States), swept away four people who were later rescued, and killed a man who was taking photos of the tsunami waves. As previously mentioned, going to the beach to watch a tsunami when a warning has been issued is suicide.

Tsunami Flow Velocity

When a tsunami reaches the coast, its characteristics change significantly, from that of a water wave to a strong inundation flow. The hydrodynamic forces of a strong inundation flow cause damage to infrastructure, buildings and people. Measuring the flow velocities of tsunami inundation on land was historically quite rare, and it was difficult to understand what had really happened in a devastated area and to identify the cause and mechanisms of structural destruction by tsunami inundation flow. However, in recent years, many tsunami survivors have attempted to capture the moment of the tsunami's assault on their communities using a videocamera or cell phone and have then uploaded their footage onto the Internet. (Note again that taking photos or videos of a tsunami should only ever be done from a position uphill, never from a beach.)

Applying a video analysis technique, the tsunami flow velocity can be determined. Here, the author presents one example from Onagawa town in Miyagi Prefecture (which had a population of 10,014 before the earthquake), which was devastated by the 2011 Tohoku earthquake tsunami. The author's investigation determined that at least six reinforced concrete or steel construction buildings were found overturned or washed away. The tsunami attacked the town of Onagawa (Figure 8) at 15:20 (35 minutes after the earthquake occurred), causing 816 fatalities. 125 people are still missing. The video from which this still was taken was filmed by a resident who evacuated to the top of a reinforced concrete building in Onagawa harbor (see arrow indicator in Figure 8).

FIGURE 8. AN OVERVIEW OF ONAGAWA TOWN, MIYAGI PREFECTURE. PHOTO TAKEN BY PASCO CORPORATION. THE RED ARROW INDICATES THE POINT WHERE THE SURVIVOR VIDEO WAS TAKEN.

Figure 9 is a still shot taken from the video, capturing the moment when houses are washed away. Using this video, the author analyzed the time series of flow depth by measuring the height of the water level on withstanding buildings shown in the video. By also focusing on the movement of drifting objects, the author was able to estimate flow velocity at the moment when the houses were washed away. Consequently, the flow velocity of the tsunami inundation was estimated as 6.3 m/s, at a flow depth of approximately 5 m. This 6.3 m/s of inundation flow caused approximately 10 tons of force per meter of wall. This hydrodynamic force easily destroyed houses.

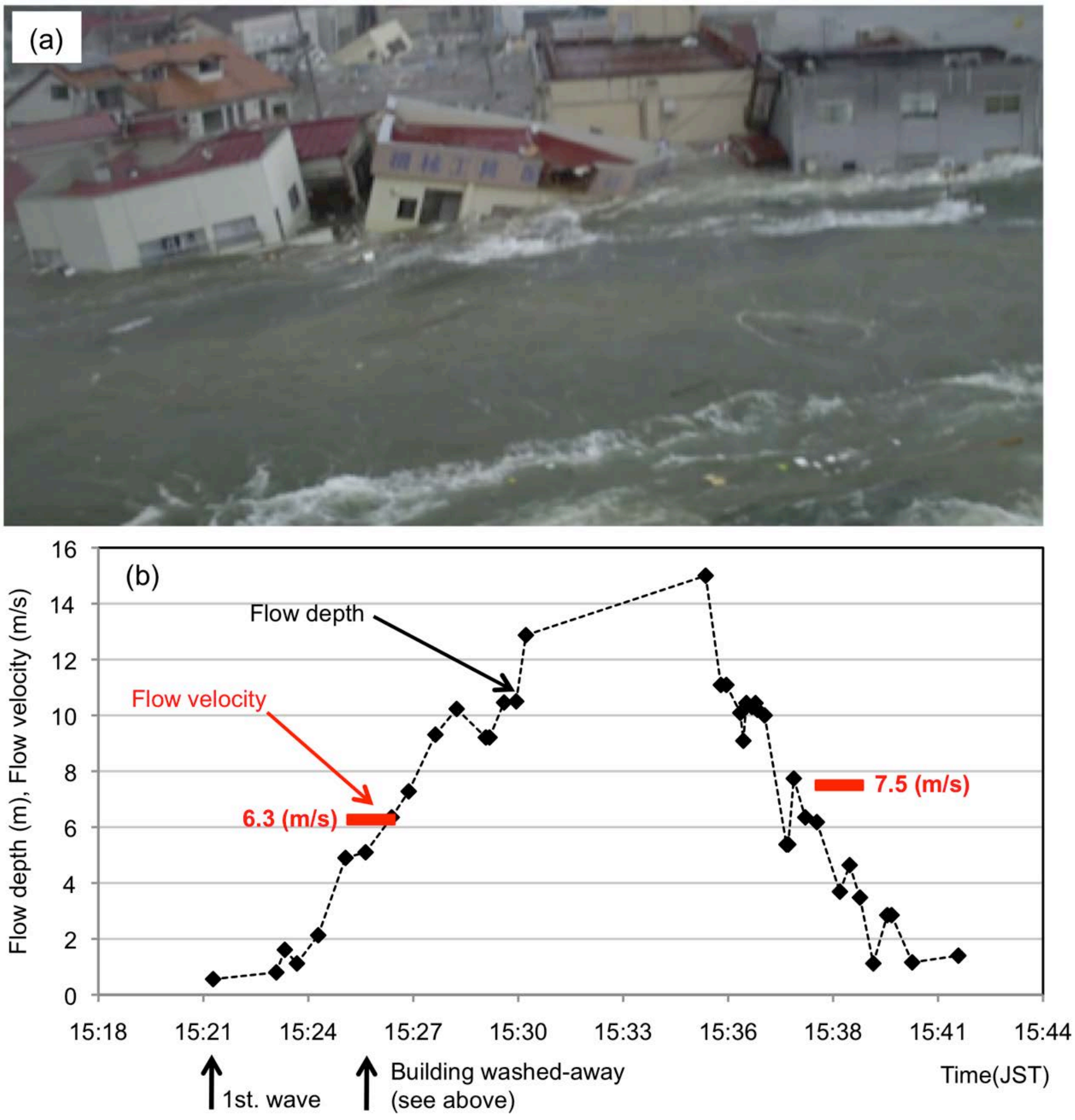

FIGURE 9 (A) A SNAPSHOT FROM THE VIDEO TAKEN BY A SURVIVOR (YOMIURI SHINBUN, 2011) CAPTURING THE MOMENT WHEN HOUSES WERE WASHED AWAY. (B) TIME SERIES OF TSUNAMI FLOW DEPTH AND CURRENT VELOCITIES, INTERPRETED BASED ON STUDY OF THE VIDEO.

Tsunami Preparedness in Coastal Communities

Tsunami countermeasures in Japan

In 1997, Japan's central government council, which consists of seven ministries, issued a guideline for comprehensive tsunami countermeasures that should be taken as part of regional tsunami disaster prevention. In those guidelines, three basic concepts of tsunami countermeasures were recommended: (1) Building seawalls, breakwaters and flood gates to protect lives and properties. (2) Urban planning to create a tsunami-resilient community through effective land use management and arrangement of redundant facilities to increase the safe area, such as vertical evacuation buildings. (3) Disaster information dissemination, evacuation planning and public education. The 2011 Tohoku event provided the first real test of the various technologies and countermeasures that Japan is using to protect people in tsunamis. Some probably worked well, while others appear to have failed (March 11, 2011, by Andrew Moore, Special to CNN).

Coastal Protection Infrastructure

In Miyagi Prefecture, north of Ishinomaki, the coastline becomes rugged and steep forming a V-shaped bay, with potential to amplify a tsunami. Since the 1896 Meiji Sanriku earthquake tsunami that killed 22,000 people, and since the more recent 1960 Chilean earthquake tsunami, Japan has developed a coastal protection infrastructure of seawalls and breakwaters. Especially in Iwate Prefecture, 10 m high seawalls have been built along the coast to protect communities that have been devastated many times throughout history.

The Kamaishi tsunami breakwater (Figure 10, following page) is in the Guinness World Book of Records as the deepest tsunami breakwater, at nearly 63 m deep. It was designed to protect the densely populated area in Kamaishi city. Its construction started in 1978 and was completed in 2006, requiring an investment of almost 30 years and 120 billion yen. But even this barrier could not protect citizens from the 2011 tsunami, although it earned them a six-minute delay before the tsunami penetrated to Kamaishi city. One can understand how, with this huge concrete breakwater, people in Kamaishi city would feel well protected, and yet the 2011 tsunami caused 1253 fatalities. The lesson is that even great seawalls can fail. Seawalls should be designed with the assumption of overtopping and destruction, and we should not rely so heavily on coastal infrastructure.

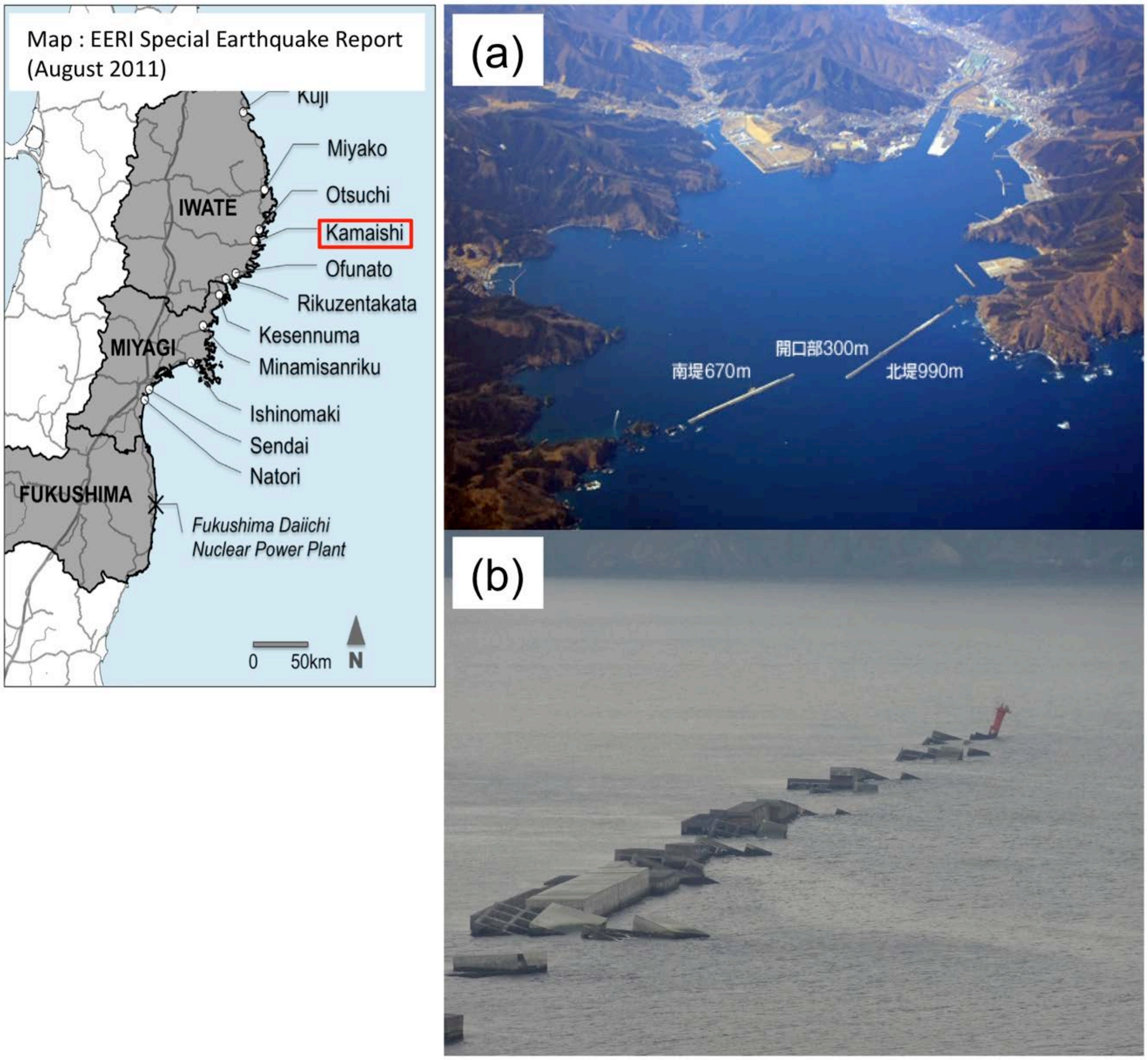

FIGURE 10 (A) TSUNAMI BREAKWATER IN KAMAISHI CITY, IWATE PREFECTURE. (B) DAMAGED KAMAISHI TSUNAMI BREAKWATER (NORTHERN PART).

Hazard Maps

It was widely believed that Japan was one of the most prepared countries in the world for a tsunami event. Was this belief correct? If so, then why were so many people killed in this catastrophic March 11 event?

In one sense, the belief **was** right. The 2004 Sumatra-Andaman earthquake tsunami (Mw 9.0-9.3) killed 220,000 people, while the 2011 event (Mw 9.0) caused approximately 20,000 fatalities, if we include those who remain missing. Both events are geologically similar with regard to the size of the earthquake and the height of the tsunami. One reason for the striking difference in the number of fatalities could be the level of preparedness.

Coastal cities and towns in Japan had prepared tsunami hazard maps with estimated inundation zones, the list of shelters where people could evacuate and instructions on how to survive a tsunami. In many coastal communities, people have conducted very regular evacuation drills and have held workshops to learn which areas are at risk, by referring a hazard map prepared by the local government. Figure 11 contrasts one hazard map for Kesennuma city, in Miyagi Prefecture, with the actual extent of inundation in the 2011 tsunami. Most readers will agree that the maps are quite similar in terms of the tsunami inundation extent.

In addition, in Sanriku coastal communities, people were taught the lesson or phrase of "tsunami tendenko," which means that "people should run without taking care of others, even family members." This phrase encourages people to escape by relying on everyone's individual decision and responsibility: each individual's effort increases the surviving possibility.

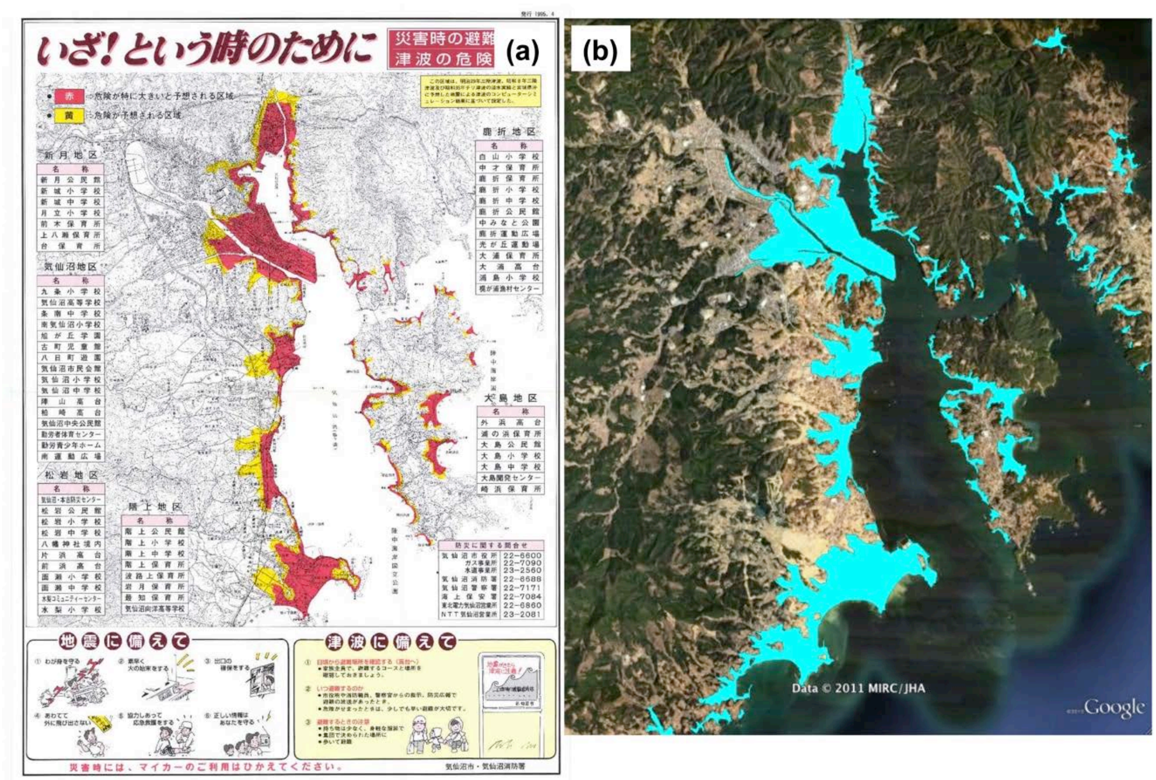

FIGURE 11 (A) TSUNAMI HAZARD MAP PUBLISHED IN KESENNUMA CITY, MIYAGI PREFECTURE, AND (B) THE MAP OF TSUNAMI INUNDATION EXTENT IN THE 2011 EVENT. THE TSUNAMI CAUSED 1,467 DEAD OR MISSING EVEN IN THIS WELL-PREPARED COMMUNITY.

At the same time, in some coastal regions, the 2011 tsunami was far more extensive than had been expected. Figure 12 shows a comparison of the expected tsunami inundation zone in Sendai city's hazard map, with the state-of-the-art computer simulation assuming M8.0 earthquake scenarios off Miyagi Prefecture, and the 2011 tsunami inundation extent. The 2011 tsunami caused much more inundation than had been estimated by the computer simulation. The lesson learned is that computer simulations cannot paint the whole picture of any disaster.

Hazard maps have two functional aspects. One is to tell people that they are at-risk. It is through such opportunities to *know* their risk that people learn that they must try to escape an at-risk area as soon as possible, when they feel strong ground motion or hear the tsunami warning or evacuation order issued. On the other hand, a hazard map can function to assure residents living outside of the expected inundation zone that their area is NOT at risk. This is one negative aspect of relying too completely on a hazard map. In the 2011 event, hazard maps failed to offer accurate predictions in some areas and may have increased the number of fatalities, as people believed that they did not have to evacuate immediately—this although the maps indicated the uncertainty of estimations based on computer simulation.

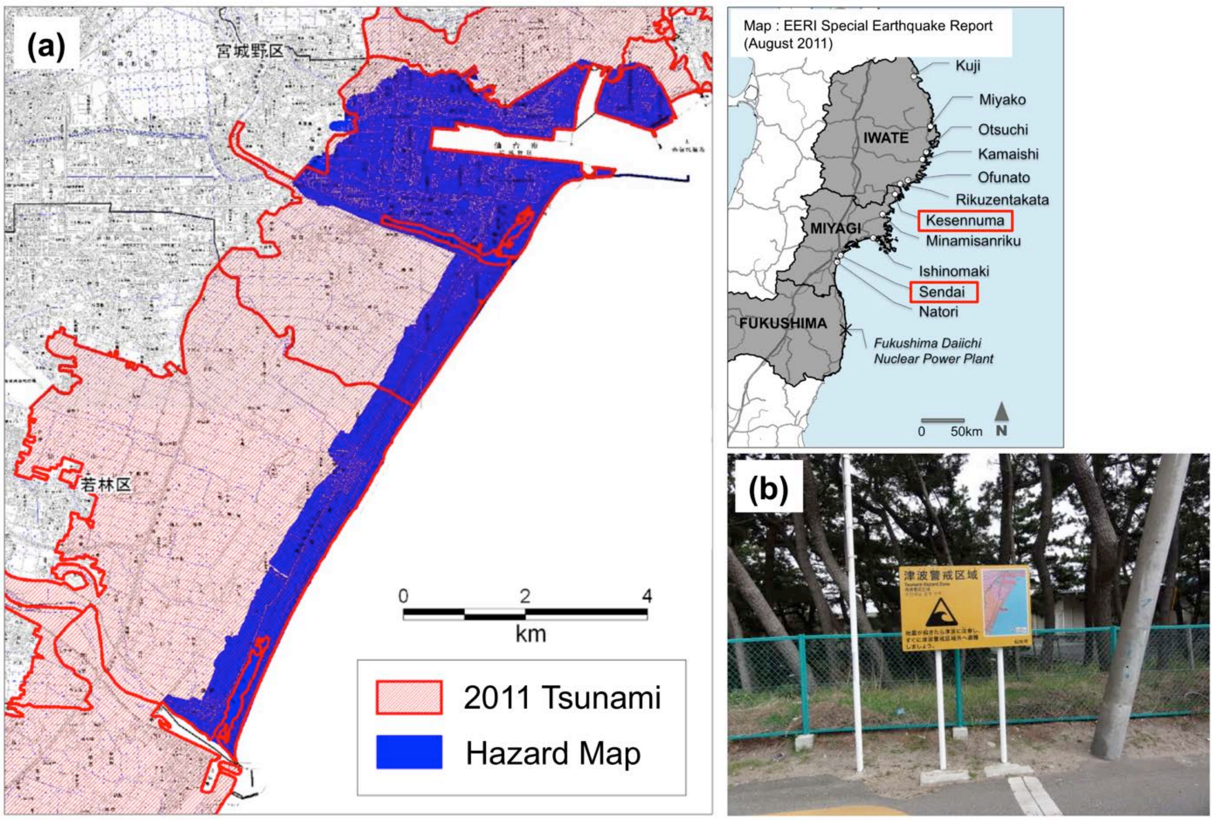

FIGURE 12 (A) TSUNAMI HAZARD MAP PUBLISHED IN SENDAI CITY, MIYAGI PREFECTURE. THE 2011 TSUNAMI INUNDATION EXTENT IS ALSO ON THE MAP FOR BASIS OF COMPARISON. (B) TSUNAMI SIGN AND INSTRUCTION WERE PUT ON THE BEACH TO WARN RESIDENTS AND VISITORS TO EVACUATE. THE TSUNAMI LEFT 755 DEAD OR MISSING IN SENDAI CITY.

Tsunami Warnings in Japan

The Japan Meteorological Agency (JMA), which is responsible for issuing tsunami warnings and for estimating tsunami height, employed a new system in 1999 and updated it using Earthquake Early Warnings (EEQ) in 2006. Japan believed that JMA's tsunami warning system was using the most advanced technology in the world. In fact, its tsunami forecasting technologies and numerical models were exported to many foreign countries that needed support. JMA prepared a pre-calculated tsunami database for over 100,000 earthquake scenarios around Japan. The contents of the warning were classified into 3 categories, according to the estimation of tsunami height: "Major tsunami" (as warning, more than 3 m of estimation), "Tsunami" (as warning, 1 or 2 m of estimation) and "Advisory" (0.5 m or less).

When the 2011 event occurred at 2:46 PM on 11 March (JST), JMA's initial estimate of the magnitude (Mj) was 7.9, using the nationwide seismic records that were not saturated.

Based on the initial estimate of magnitude 7.9, three minutes after the quake, JMA issued a tsunami warning to the coasts of Iwate, Miyagi and Fukushima Prefectures with the estimates of 3 m, 6 m, and 3m, respectively. After the tsunami was observed at offshore tsunami buoys, JMA revised the contents of the warning with estimates of 3 m, 6 m, over 10 m, 6 m, 4 m to the coasts of Aomori, Iwate, Miyagi, Fukushima, Ibaraki and Chiba Prefectures (see Figure 13). Receiving the tsunami warning from JMA, some residents claimed that they thought they were safe based on the 3 m estimation; they did not feel that they had to evacuate, since they felt safe behind a 10 m seawall. Even worse, in several communities, the radio or speaker system did not work because of the blackout caused by the earthquake.

Now, JMA has started planning to expand its seismic/tsunami monitoring network by installing broadband seismometers and offshore tsunami monitoring system, to increase its capability for quicker and more accurate estimation. However, there are limitations on the reliability of science and technology that can be used in such a limited amount of time. Tsunami warning information can inform people that they are in danger, but it cannot guarantee people's safety. The most important lesson is that one should not wait for official information to act: strong ground shaking is the first alert to take action, in order to survive.

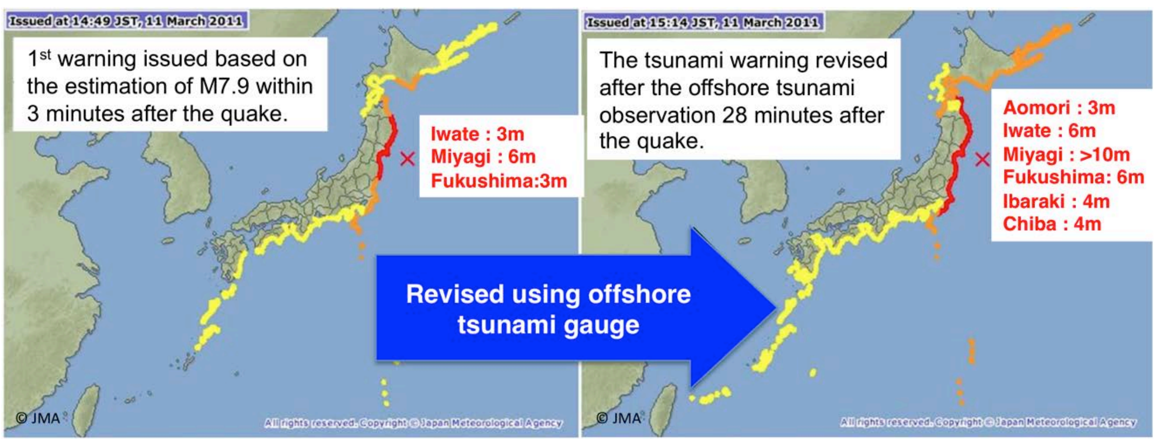

FIGURE 13 THE JMA TSUNAMI WARNING ISSUED AND REVISED IN THE AFTERMATH OF THE 2011 TOHOKU EARTHQUAKE.

Structural Vulnerability to Tsunamis

Structural vulnerability to tsunamis is a critical issue in planning for tsunami-resilient communities. Figure 14 shows the result of mapping building damage in Ishinomaki city by interpreting aerial photos that the Geospatial Information Authority of Japan acquired of the devastated area. By mapping the structural damage and overlooking its spatial distribution, not only the impact of tsunami, but also the protective effect of coastal infrastructure and vegetation can be seen.

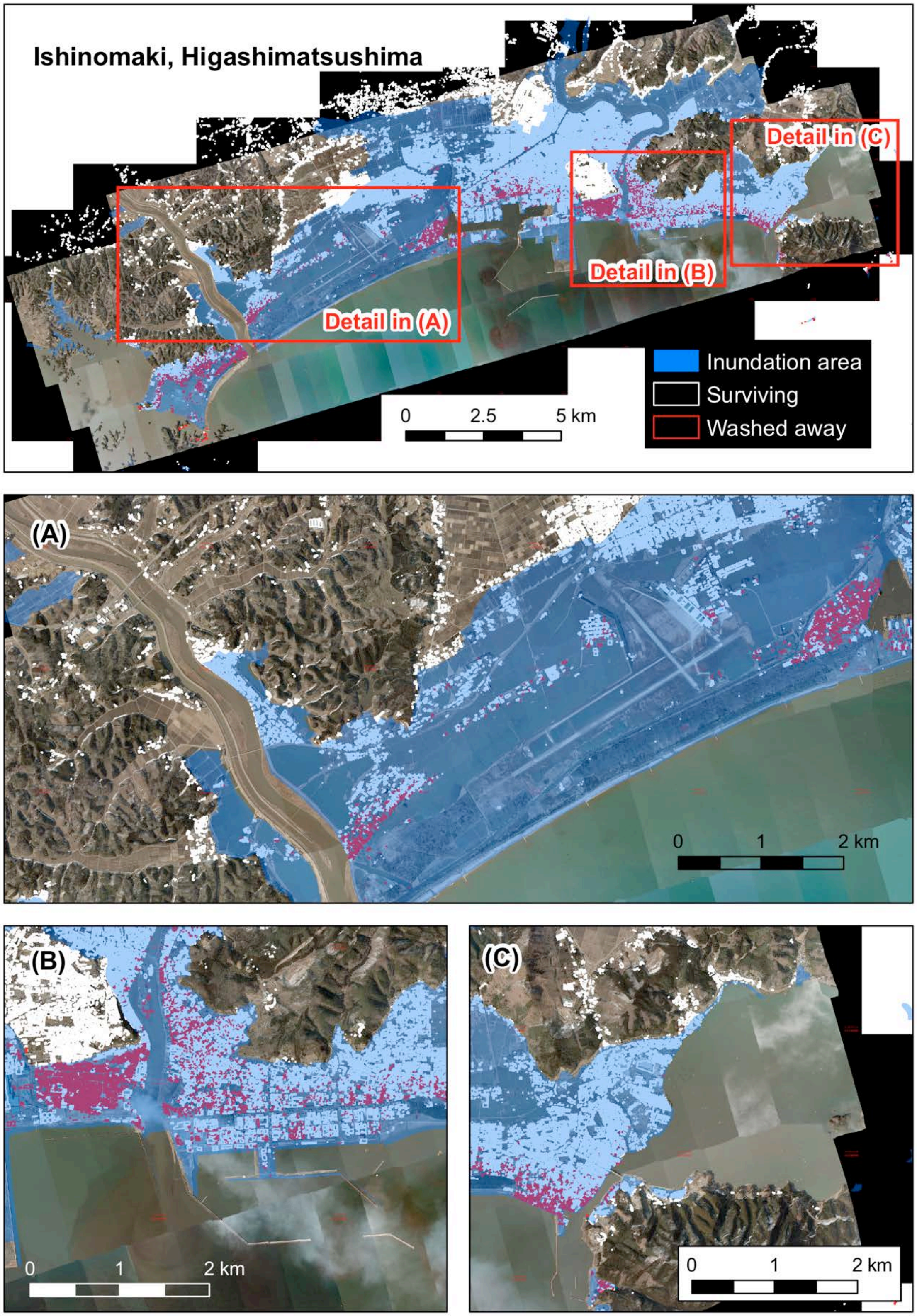

FIGURE 14 MAPPING BUILDING DAMAGE BY INSPECTION OF POST-EVENT AERIAL PHOTOS.

Integrating structural damage mapping with field survey data, such as flow depths (Figure 15), produces a new measure of structural vulnerability to tsunamis, as a form of tsunami fragility curve or tsunami fragility function. A tsunami fragility curve is defined as the structural damage probability or fatality ratio with particular regard to the hydrodynamic features of tsunami inundation flow, such as flow depth, current velocity and hydrodynamic force. The tsunami fragility curve is preliminarily obtained as shown in Figure 16 (following page). The fragility curve shown in the figure indicates the damage probabilities of structural destruction equivalent to the flow depth. Structures in Miyagi Prefecture were especially vulnerable when the local flow depth exceeded 2 m, while a 6 m flow depth would cause everything to be washed away. This finding can inform land use planning (zoning), so that residential areas will not be inundated more than 2m.

Figure 15 shows a spatial distribution of flow depths measured in the tsunami inundation zone. Spatial interpolation of measurement data (point data) to obtain raster data is combined with the structural damage mapping (e.g. Figure 14).

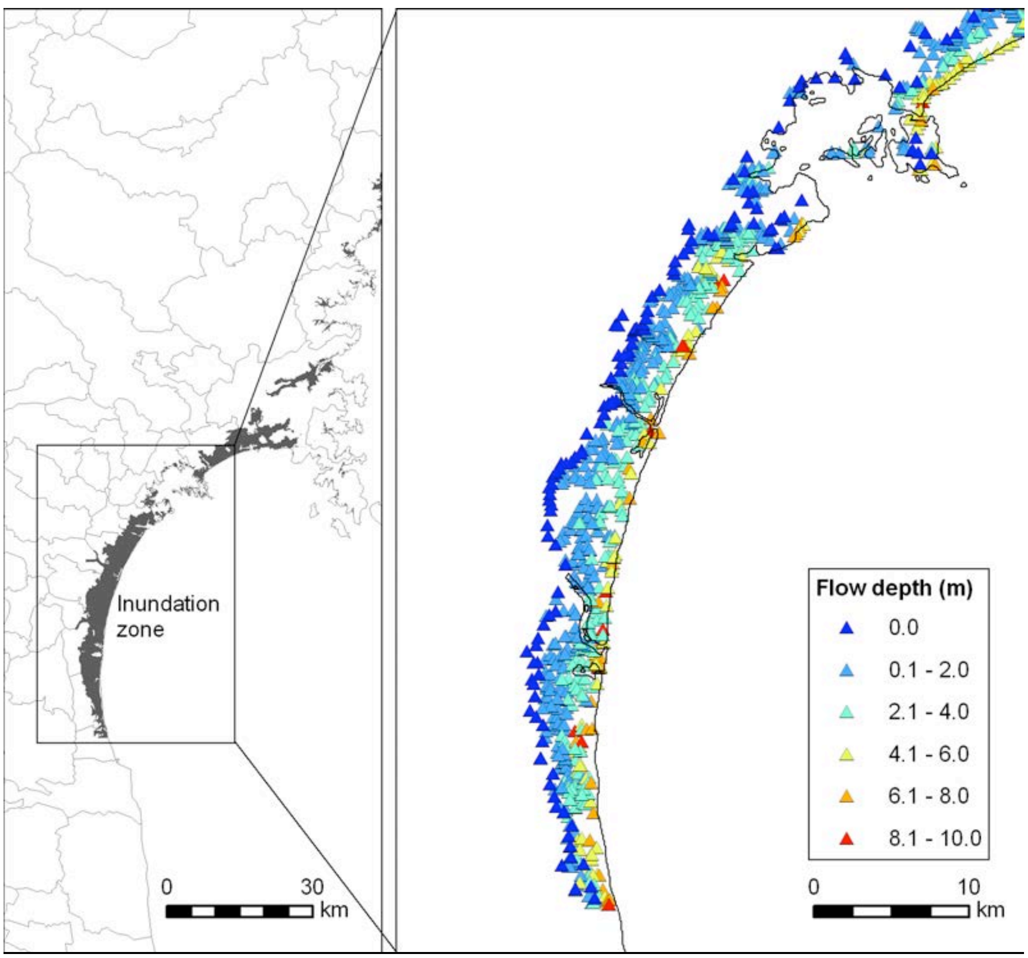

FIGURE 15 MAPPING THE TSUNAMI FLOW DEPTH MEASURED BY MIYAGI PREFECTURE AND THE POST-TSUNAMI SURVEY TEAM.

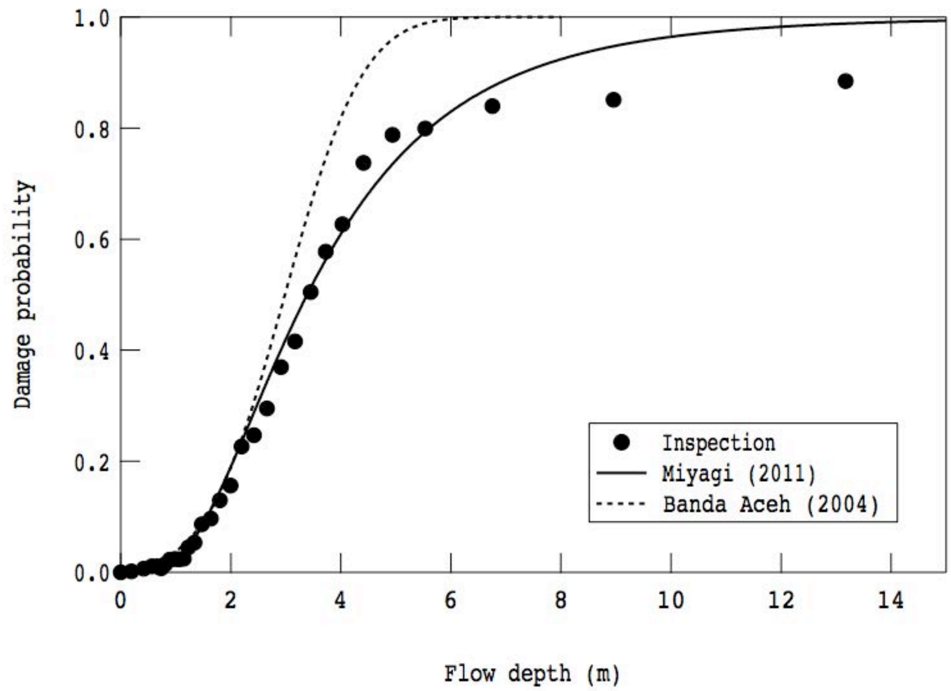

FIGURE 16 TSUNAMI FRAGILITY CURVE FOR STRUCTURAL DESTRUCTION (WASHED-AWAY STRUCTURES). THE SOLID LINE IS OBTAINED FROM MIYAGI PREFECTURE (FROM THE 2011 EVENT) AND THE DASHED ONE IS FROM BANDA ACEH, INDONESIA (THE 2004 INDIAN OCEAN TSUNAMI).

The Tsunami's Impact on Schools – Tragedy in Okawa Elementary School

Many pupils and teachers were affected by the 2011 Tohoku earthquake and tsunami. On 6 October 2011, Japan's Ministry of Education, Culture, Sports, Science & Technology published a report of student fatalities and injuries: in total, 635 children, students and teachers were killed by the tsunami, and 221 were injured.

Especially hard hit was Okawa elementary school in Ishinomaki city, located 5 km inland along the Kitakami river: the school lost 74 pupils (70 killed and 4 still missing) out of a total of 108 and 10 teachers (9 killed and 1 still missing) in the 2011 tsunami (Figure 17). At least 50 minutes elapsed after the earthquake, before the tsunami attacked the school. After the strong ground shaking had stopped and the tsunami warning had been issued, the teachers and pupils gathered on school grounds to discuss where to go.

They had two options. One was a hill with a steep slope behind the school, which looked difficult for small children to climb. The other was a small overlook at the river bridge, 200 m away from the school. Consequently, teachers decided to head for the bridge, walking along the river. Shortly thereafter, the tsunami penetrated along the river and overtopped the riverbank, sweeping away pupils and teachers.

The causes of their deaths are still under investigation by the Ishinomaki city educational council. But we must learn the lessons of this sad incident. What is the requirement that should be put into place for safer school buildings that can withstand both strong ground shaking and a devastating tsunami—how much building height must be required, so that the inhabitants can survive? (The Okawa elementary school building withstood the devastating tsunami inundation flow but was totally submerged.) How we can educate children to be prepared? How should teachers be trained to provide appropriate guidance to save children's lives and their own?

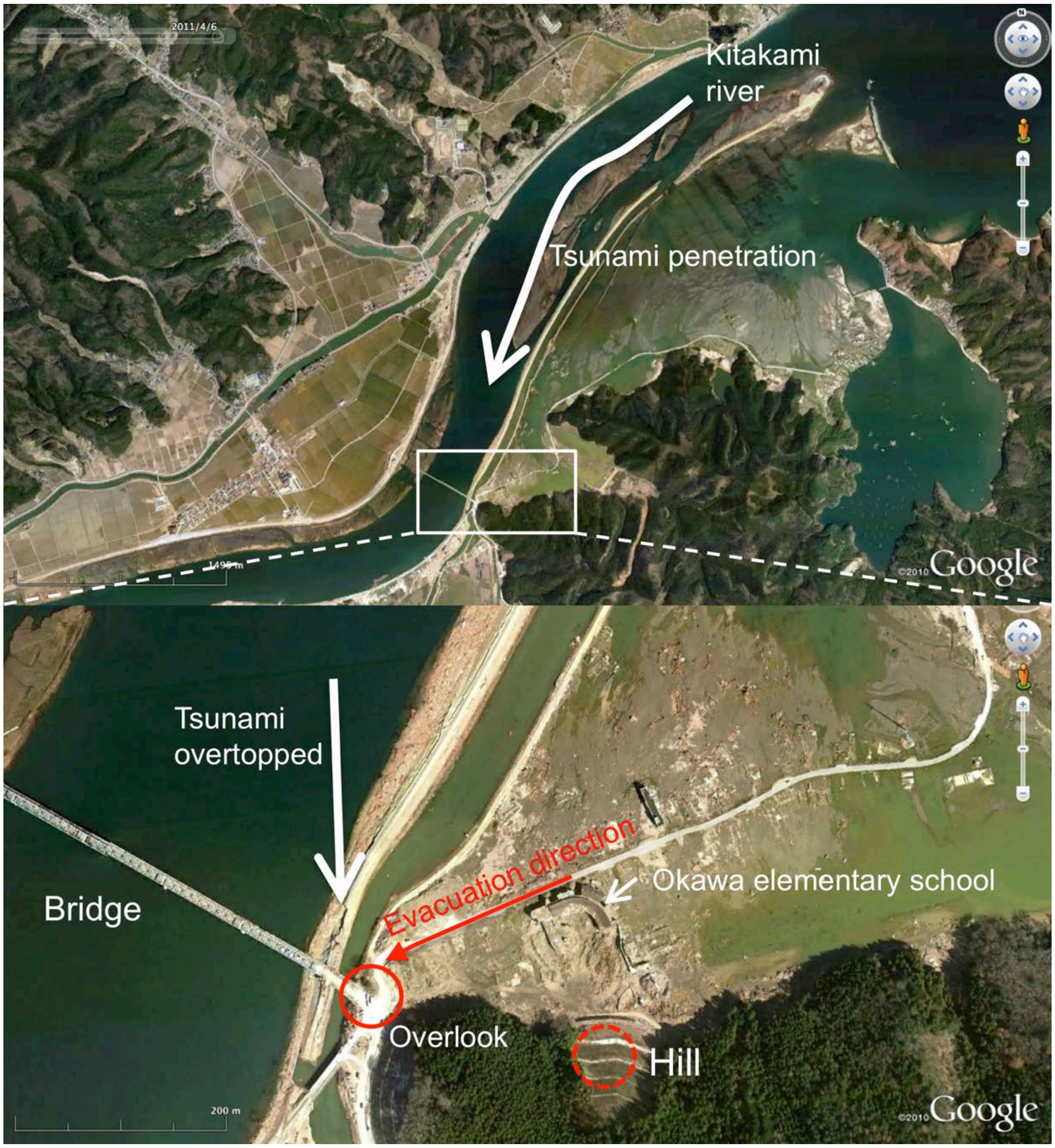

FIGURE 17 OKAWA ELEMENTARY SCHOOL DEVASTATED BY THE 2011 TOHOKU TSUNAMI. THE TSUNAMI KILLED 74 OKAWA PUPILS AND 10 TEACHERS, WHO WERE ON THEIR WAY TO AN ELEVATED BRIDGE.

Summary

The 2011 Tohoku earthquake and tsunami offer valuable lessons that should be applied, in order to build safer and more resilient coastal communities:

- Know which areas are at risk. This is critical, but one must also recognize the predictive limits of science and technology.
- Governments can reduce risk, but communities must not become complacent. Computer simulations cannot predict everything that will happen in a disaster. Hazard maps cannot always accurately predict areas at risk.
- Coastal infrastructure such as breakwaters and seawalls cannot always protect life and property: even great seawalls can fail. Seawalls should be designed with the assumption of overtopping and destruction, and communities should not rely on coastal infrastructures alone for protection.
- Never go to the coast to watch a tsunami! If you do, then you must run faster than motorcycles to survive it.
- To survive a tsunami, evacuate to a higher place as soon as possible. The place for evacuation should be discussed in advance among family members. Find a safe place that you can reach within several minutes. If you can walk or run, then do not use a car.
- As observed in devastated areas in Japan, tsunami flow depth over 2 m has potential to severely damage houses.
- Highrise reinforced concrete buildings with robust columns and walls can withstand tsunami flow depth over 2 m and can be used for vertical evacuation.
- School buildings should have similar construction requirements, in order to ensure children's safety.
- Teachers, parents and children should have more opportunities to learn about their risk and how to survive in emergency situations.
- Citizens should find out how what disaster information resources are available, but they should not rely exclusively on official information in an emergency. Strong ground shaking will be a first alert to take action, in order to survive a tsunami.

Acknowledgements

The post-tsunami field survey was conducted by a group of 20 scientists and engineers. All the data of the team's measurements can be found online at http://www.tohoku--tsunami.jp/

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Volcanic Hazard Issues for Schools

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Executive Summary

The Asia-Pacific region hosts more than 80% of the known volcanoes on Earth. However, most individual communities of the region are affected so rarely by volcanic eruptions that school children are more likely to learn of volcanoes from textbooks or TV than from their grandparents. Fortunately, because volcanoes give ample warning signs before they erupt, public education and short-term evacuations are practical and effective mitigation measures. Longer-term mitigation measures such as land use planning and special siting and construction for schools are most easily sustained in communities that experience frequent eruptions.

Instantly fatal volcanic hazards, e.g., searing hot blasts of sand and rock, are typically restricted to a zone of 10-20 km radius around a volcano. Slower moving volcanic mudflows ("lahars") can bury towns at greater distances, especially on valley floors, but warning systems can be installed to evacuate citizens in time. Damage from hot blasts or mudflows is severe and prior evacuation is the only realistic mitigation option. A gentle rain of ash can affect broad areas up to hundreds of kilometers from a volcano but in most cases residents can remain in their homes and mitigate damage by covering or cleaning property.

The most likely effects on students and teachers near a volcano, whether as evacuees or as hosts to evacuees, will be prolonged disruption of classes. In a best-case scenario, evacuation will last just a few days, but some evacuations have lasted for months; in more extreme cases, whole towns have been buried and must be relocated and rebuilt.

Twenty years ago, a large explosive eruption of Mount Pinatubo, Philippines, swept and buried mountain slopes to a radius of about 15 km. An indigenous population of ~20,000 was evacuated days before the climactic eruption, and only a few schools were swept away. However, heavy, wet ashfall caused many school roofs to collapse at distances out to 50 km (official tally: 700 school building with 7400 classrooms destroyed as of August 1991), and rain-induced lahars (volcanic mudflows) over the succeeding decade buried many additional schools around Pinatubo and displaced ~200,000 people (figures1a, b). Good warnings and large-scale evacuations and relocations were largely successful in keeping people out of harm's way, but classes for primary and secondary students were seriously disrupted, and many students had to withdraw from school, because their parents lost jobs, businesses, or farms and could no longer afford to pay their tuition and other costs. Only some of those who withdrew could later re-enroll. The disruption was prolonged and it was not until a decade later that the economy of the region had largely recovered.

FIGURE 1A. "SCHOOL'S OUT!" KIDS ON ROOF OF LAHAR-BURIED SCHOOL BUILDING, BAMBAN, TARLAC, PHILIPPINES, 28 KM NORTHEAST OF PINATUBO. PHOTO, C NEWHALL, USGS.

FIGURE 1B. TWO GENERATIONS OF SCHOOL BUILDINGS IN SANTA BARBARA, BACOLOR, PAMPANGA, PHILIPPINES, 30 KM SOUTHEAST OF PINATUBO.

More details of the eruptions and lahars of Pinatubo, and their effects, are available online at http://pubs.usgs.gov/pinatubo.

Volcanoes and Volcanic Eruptions

Tens to hundreds of kilometers beneath the Earth's surface, heat, water, and decompression act to melt small fractions of pre-existing rock; the result (known as magma) rises toward the Earth's surface. As it reaches within a few kilometers of the Earth's surface, magma heats water-saturated rock layers, so that the first phase of an eruption may consist purely of steam (vaporized groundwater) and pulverized pre-existing rock – what's known as a "phreatic" eruption. If magma reaches the surface, then it will erupt either explosively (blowing the magma into fragments large and small), or effusively (simply pouring or oozing lava out of a vent). It is common for eruptions to start as phreatic. Whether or not they will become magmatic is an important question, because magmatic eruptions are far more hazardous.

Volcanoes are geologic structures from which material is erupted from depth into the atmosphere or onto the surface of the earth. Most successive eruptions build volcanic mountains. When explosive and effusive eruptions alternate (producing fragmental or "pyroclastic" debris and lavas, respectively), they build steep-sided "stratovolcanoes" such as Mount Fuji or Mayon Volcano (figure 2a). Effusive eruptions of fluid magma build gently sloping "shield" volcanoes (e.g., Mauna Loa in Hawaii, figure 2b); effusive eruptions of viscous (meaning sluggish, pasty) magma build lava domes (e.g., Mount St. Helens , figure 2c). Some volcanoes change their behavior from time to time and are a composite of two or more of the abovementioned types.

FIGURE 2A. MAYON VOLCANO, PHILIPPINES. PHOTO BY PHIVOLCS

Unusually large explosive eruptions can also create large craters or calderas (e.g., Long Valley caldera, eastern California; Toba caldera, north Sumatra). The deposits from large caldera-forming eruptions are spread so widely that one hardly recognizes the feature as a volcano; rather, these huge volcanoes can appear to be broad topographic basins.

Moderately large explosive eruptions can create small calderas in the summits of stratovolcanoes, e.g., Crater Lake in ancient Mount Mazama, Oregon (figure 2d), or the 2.5 km diameter caldera that formed in Mount Pinatubo in 1991.

FIGURE 2B. MAUNA LOA SHIELD VOLCANO, HAWAII

FIGURE 2C. LAVA DOME OF MOUNT ST. HELENS, 1984. PHOTO BY L. TOPINKA, USGS

FIGURE 2D. CRATER LAKE CALDERA, OREGON, 10 KM ACROSS, FORMED AFTER GIANT ERUPTION 7000 Y AGO. PHOTO BY W. SCOTT, USGS

Where Do Volcanoes Grow?

A wonderful, interactive map of volcanoes (and earthquakes) of the world is available online from the Smithsonian Institution's Global Volcanism Program, at http://nhb-arcims.si.edu/ThisDynamicPlanet/index.html. Volcanoes are subdivided on that website into those which have erupted since 1900 AD, since 0 AD, and since about 10,000 years ago. Volcanoes are sometimes classified as (a) active, (b) dormant, or (c) extinct. Active volcanoes are those that have erupted within recorded history. Dormant volcanoes have not but show other signs of life, such as hot springs or fresh-looking eruption deposits. Extinct volcanoes are thought to be incapable of future eruption. However, this classification system is imperfect and several so-called extinct volcanoes have re-awakened! Whether a volcano is still capable of eruption depends mainly on the volume of magma beneath it.

The smallest volcanoes (e.g., small cinder cones) can erupt for a few years or centuries and then become extinct. In effect, a small batch of magma finds a pathway through the Earth's crust and part of it erupts. Whatever magma is left in the conduit cools and solidifies. Most stratovolcanoes, shield volcanoes, and dome complexes grow over magma reservoirs that stay molten from one eruption to the next, receiving magma influxes from below every few months to decades and sending magma upward toward the surface once every few months to millennia. Magma reservoirs can grow or shrink with time, depending on the balance of fresh supply and eruptions. Most geologists consider stratovolcanoes, shield volcanoes, or dome complexes that have erupted within the past 10,000 years to be capable of future eruption.

Giant caldera-forming eruptions occur after a large volume of gas-rich magma accumulates for centuries, millennia, or longer. These largest magma reservoirs have the capacity to absorb many episodes of fresh magma supply from depth, and thus to remain quiet but capable of eruptions for up to a million years!   Toba Caldera in north Sumatra produced giant eruptions 1.2, 0.8, and 0.074 million years ago; Yellowstone caldera in Wyoming did the same 1.8, 1.2, and 0.6 million years ago. One consequence of this absorbing or "buffering" capacity is that these volcanoes with the potential for the largest explosive eruptions can also exhibit many "false-alarm" episodes of unrest that will not culminate in eruptions.

A small shortcoming of the interactive map, This Dynamic Planet, is that it doesn't display the names of the volcanoes. However, there are two other resources where you and your students can easily find volcano names and additional information. First, the Smithsonian Global Volcanism Program has partnered with Google Earth and other online maps, so that as you look at your area in those maps and satellite images, you will find the names of the volcanoes located there. In some cases, you'll find a brief description of the volcano as well. Second, more detailed information about terrestrial and a few submarine volcanoes may be found at http://www.volcano.si.edu. That information includes eruptive history, maps, photos and more.

What Makes Volcanoes Erupt?

In a word, gas. Magma (molten rock) contains water, carbon dioxide, sulphur, and other gases that remain dissolved until the magma nears the Earth's surface. There, under lower confining pressure, the gases exsolve (which is the opposite of dissolve) into bubbles that expand if they can, or build up pressure if they cannot expand. Think of a bottle of a carbonated soft drink that you just shook and then opened. The first thing that will happen will be an explosive eruption. After the soft drink goes "flat," then the best that it can produce is a weak overflow. Magma behaves in the same way as that carbonated soft drink, with an important difference that magma is fed from a large, rechargeable reservoir long after the bottle of soda would have gone flat.

What are the Main Volcanic Hazards?

If a picture is worth a thousand words, then a video of volcanic hazards is worth much more! APEC workshop attendees received a DVD of a video that concerned volcanologists made after an awful and fully preventable mudflow disaster killed more than 23,000 people in Colombia in 1985. The video was completed just before the eruption of Mount Pinatubo in the Philippines and saved MANY lives. Residents of the Pinatubo area had no historical experience with eruptions and words and maps from volcanologists were hard for most people to understand. Fortunately, this video was so graphic that it convinced people to heed recommendations and orders for evacuation.

The first hazard described in the video is "hot ash flows," also known as pyroclastic flows or "nuees ardentes" (glowing clouds). These hot avalanches or blasts of sand, rock, and steam have temperatures up to 800^{o}C, and travel 50-100 km/h and sometimes faster. They tend to follow river valleys but can easily skip overbank and across a volcano's slopes. They instantly kill all life in their paths, and destroy most buildings as well. The only protection against pyroclastic flows is prior evacuation. A few scientists argue that pyroclastic flows are survivable in a sturdy building, but one's chances of survival are vanishingly low.

The second hazard described in the video, a volcanic mudflow (lahar), forms when loose volcanic debris mixes with water from rains, melted snow and ice, crater lakes, or groundwater that has been squeezed or pushed out of the volcano. Lahars can be hot (up to 100^0C) or cold and can travel 20-50 km/hour on steep slopes and 5-10 km/hour on gentle slopes. In active lahar channels, entire bridges and buildings can be lifted and carried away. Outside of the main channel, lahars will spread and bury communities to depths of 1 to several 10's of meters or, rarely, more. The two generations of schools near Pinatubo in figure 1b were buried by repeated lahars to a depth of about 12 m on a broad, gently-sloping apron of volcanic debris about 30 km from the volcano summit. It would be possible to build schools up on sturdy stilts, but if the school community is buried, why bother? A more useful approach is to site schools on high ground, where they can double as a refugee center for anyone who has built on more vulnerable lowland.

The third feature of explosive eruptions described in the video is volcanic ashfall (also called tephra fall). Debris is lofted high above a volcano, where winds of the day carry it in one or several directions before it rains back onto the Earth. Technically, ash consists of sandy or silty particles <2 mm in diameter, but some gravel-size rocks can also be carried in eruption clouds and can drift as far as tens of km away from the volcano before raining out of the cloud. The biggest hazard of ashfall to schools is that it may accumulate on school roofs and cause them to collapse. It would be safer to stand outside in a rain of ash and small pumices than to remain inside a building with thick ash accumulating on the roof. An even better choice would be to get into a vehicle or into a small building with a steep roof. Aside from safety concerns, ash is also a significant nuisance, abrading and jamming machines and engines, damaging crops, causing respiratory irritation, and, like dust, getting into every nook and cranny of a house, office building, computer, HVAC system, etc. Wise building operators will keep filters on hand to keep ash out of central air-conditioning and ventilation (HVAC) systems. If no specialized air filter is available, nylon stockings can help.

The fourth hazard of the video is lava, a flow of molten rock. On some steep slopes, lava is fluid enough to behave as a fast-moving river that can reach 10's of kilometers from a vent. More often, it moves sluggishly for 1-10 kilometers from the vent. The most sluggish lavas can't flow at all, so they just mound up around a vent in what we call lava domes. On a flat surface domes are not very dangerous, but at the summit of a steep volcano, they often collapse and send rocky pyroclastic flows into nearby lowlands. No building can withstand a lava flow (or a pyroclastic flow). However, in a few places with especially fluid lavas, lava flows can be diverted away from key buildings or towns by large-scale levees.

The fifth hazard, volcanic landslides, came into many peoples' awareness after a giant landslide from Mount St. Helens, Washington State, in 1980. The entire summit and north flank slid into the adjoining valley. 2.5 km3 (i.e., 2.5 billion m3) of deposit filled the Toutle River Valley to depths as great as 200 m. Such events are relatively rare, but one will occur on average every few tens of decades, somewhere in the world. Because the landslide at Mount St. Helens unroofed a hydrothermal (hot groundwater) system and magma beneath, it unleashed a strong blast (pyroclastic flow) as well. Today, chances are that scientists will detect and warn of a potential volcanic landslide, but it will still be a challenge to forecast whether and exactly when it might occur. Giant landslides preceded by visible bulging of a volcano will be marginally easier to forecast than those that occur because groundwater within the volcano gets pressurized and acts like a lubricant to trigger a giant landslide.

If a large volcanic landslide or voluminous pyroclastic flow enters the sea, then it can displace seawater and generate a volcanic tsunami. In most cases, effects are restricted within distances of just a few hundred kilometers, but these local effects can be severe. The greatest death toll from the famous 1883 eruption of Krakatau was not from the eruption but rather, from volcanic tsunami, and the same was true near Mount Unzen in Japan in 1792.

The sixth hazard is volcanic gas. Thanks to Hollywood movie depictions, volcanic gases have a much more dangerous reputation than they actually deserve. Only in rare circumstances will carbon dioxide (CO2) gas accumulate in topographic lows and kill people by starving of them of oxygen. The worst known case, shown on the DVD, occurred in Cameroon in 1986. More often, winds and convex topography of a volcano will disperse gases. Some gases are acidic (sulphuric and hydrochloric acid) and can damage crops and corrode metals.

The last hazards mentioned in the video, volcanic earthquakes, tend to be small and are only rarely damaging. They are more worrisome as possible eruption precursors than by themselves. Ground deformation and ruptures are also usually imperceptible and of more concern as eruption precursors than by themselves. However, in the rare case that a volcano starts to grow directly under your community (as in Toyako Spa town, Japan), that swelling/ inflation of the ground may destroy everything.

The two sidebars that follow describe the two hazards that are most likely to affect communities located at or beyond the feet of volcanoes.

Case history: lahar hazard

The people of Colombia, of the international volcanological community, and of the world were shocked in November 1985 when a relatively small eruption of Nevado del Ruiz volcano melted snow and ice in the summit region and sent massive lahars down several river valleys. The worst came down the Lagunillas River and destroyed the city of Armero (figure 3). More than 20,000 residents of Armero were killed and only about 9,000 survived. The DVD that accompanies these notes ("Understanding Volcanic Hazards") was an agonized response of "Never Again!" from volcanologists. Scientists had warned the people of Armero that if Nevado del Ruiz erupted, they would be in great danger from mudflows ("flujo de lodo"). They warned people again when the eruption did occur, but very few people left their homes, even though they could have walked to safer, high ground. The technical term "flujo de lodo" didn't sound very threatening, and people had no idea that they were about to be swept away by a 2-5 meter wall of water, mud, rocks, and logs.

FIGURE 3. OVERVIEW OF LAHAR-COVERED ARMERO. MORE THAN 20,000 PEOPLE FROM THE NOW-GRAY AREAS DIED, AND ANOTHER 3,000 DIED IN CHINCHINA TOWN. PHOTO BY R. JANDA, USGS

Case history: lahar hazard

Mount Rainier, in Washington State, is similar to Nevado del Ruiz in that it is covered with snow and ice and has a history of giant lahars. Some Rainier lahars originate as giant landslides that evolve into lahars as they flow. Other Rainier lahars form by eruption of hot debris across snowpack. The City of Orting, Washington, lies where the Carbon and Puyallup Rivers from Mount Rainier join and flow onto the surrounding Puget lowlands (figure 4a), a setting much like that of Armero, Colombia. Geologists have known for decades that Orting and other nearby towns are built on deposits of geologically young lahars. The site of Orting was last buried by a lahar about 500 years ago – long in the memory of people but short in the lifetime of a volcano. Excavations in the town routinely encounter huge tree stumps that were snapped, buried and preserved by the 500-year old lahar. Orting is a fast-growing community and development brings subdivisions, families with children, and schools (figure 4b).

FIGURE 4A. AERIAL VIEW OF ORTING, 1992, LOOKING UPSTREAM. CARBON RIVER AT LEFT AND PUYALLUP RIVER AT RIGHT.

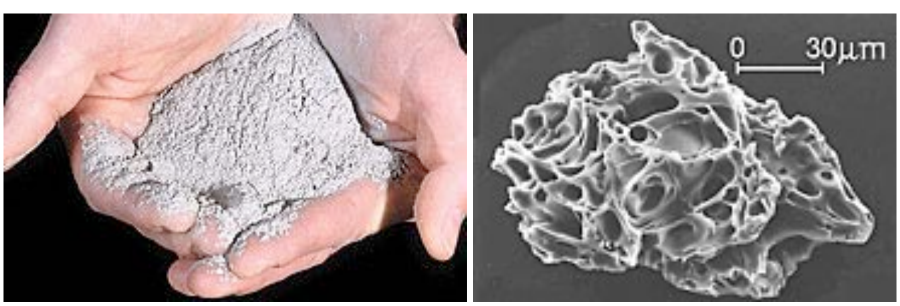
The Washington State Growth Management Act of 1990 and a 1991 County ordinance limited development in lahar hazard zones, forcing local citizens and officials to assess their risk and consider mitigation measures. School safety is especially sensitive, and several Orting schools are close to safe, high ground but separated from it by one of the two rivers that could bring a lahar. In response, concerned parents of Orting promoted and have obtained promises of partial funding for a USD 12 million pedestrian bridge that could get students and teachers out of lahar danger more quickly than any evacuation using school buses or other vehicles. However, in an era of government budget reductions, proponents are still trying to secure the balance of funding needed to actually build the bridge. The parent organization Bridge4Kids (http://www.bridge4kids.org) has convinced many of the need for funding, but it still meets opposition from some who argue that it is too big an expense for a bridge that might never be needed.

In the meantime, two other precautionary measures are in place. The first is a system with sensors high enough on the volcano slopes to provide at least 30 min of advance warning, coupled with emergency sirens. The second is an annual evacuation drill in the Orting schools, requiring evacuation along routes illustrated in the City Lahar evacuation plan (http://www.cityoforting.org/Lahar_Information.html; http://www.cityoforting.org/uploads/Lahar_Evac_Map.pdf), longer than the route of the proposed Bridge4Kids. All agree that immediate evacuation is the only safe action in the event of a lahar.

FIGURE 4B SCHOOLYARD IN ORTING, WASHINGTON, WITH SNOW-COVERED MOUNT RAINIER IN BACKGROUND. SEVERAL SCHOOLS ARE CLOSE TO THE CARBON RIVER AND SAFETY FROM LAHARS, IF A PEDESTRIAN BRIDGE CAN BE BUILT ACROSS THE CARBON RIVER. PHOTO FROM ORTING BRIDGE FOR KIDS,

Tephra fall- a rain of pebbles, sand and dust

Recall the bottle of carbonated soda that you shook and opened earlier. First, foam quickly developed as soon as you popped open the top. The bubbles expanded so much and so quickly that they burst, creating a spray of tiny droplets of soda. This is what happens during explosive eruptions. The magma develops a foam, which expands so fast that it blows itself into dust-size and larger particles that solidify quickly. The fine particles are volcanic ash (figure 5a); the larger fragments, ranging in size from pebbles to meter-scale, are called lapilli and bombs respectively. Together, all are called "tephra." The larger particles may be solidified foam, still full of tiny (bubble) holes and now called pumice or cinder (figure 5b). Most bombs land within 5 km of a summit; lapilli might reach tens or even a hundred km downwind, and ash can reach 100's and even 1000's of km downwind.



FIGURES 5A, 5B. ASH FROM MOUNT ST. HELENS, 1980. (A) ASH IN HANDS, UNMAGNIFIED. (B) PUMICEOUS ASH AS SEEN UNDER SCANNING ELECTRON MICROSCOPE. THE SPONGE-LIKE TEXTURE IS FROM THE MAGMA FOAM, QUICKLY SOLIDIFIED UPON ERUPTION. PHOTO CREDIT: USGS

Near a volcano, tephra can accumulate to thicknesses of several centimeters or, in rare instances, several meters. If tephra is wet by rain, the weight of 10-20 cm of ash can be as much as 200-300 kg/m^2, which can cause weak roofs to collapse. Roofs in snow-country are built to withstand snow (or ash); roofs in the tropics are not. In the tropics, ashfall of 5 cm or more will collapse the weakest roofs. In the area around Vesuvius, scientists estimate that thicknesses of ~ 250 kg/m^2 will cause 50% of the weakest roofs to fail (Zuccaro et al., 2008). Schools, churches, shopping malls, and other public buildings tend to have large roofs with long spans and low pitches. Without adequate support, they are the most vulnerable to collapse (figure 6). One obvious solution in ash-prone areas is to build stronger and/or steeper roofs. Another is to move from large buildings into smaller but sturdy buildings. It would make sense to clear ash from roofs as it is falling, but during storms that often accompany eruptions, rain will make the ash sticky and slippery, and the lightning will be frightening to people. Acid droplets covering ash particles will quickly corrode a metal roof.

Ash poses a small but non-negligible risk to human health, especially for those people who have pre-existing respiratory ailments. Healthy individuals can cough out small amounts of ash; those with emphysema, asthma, or other respiratory problems cannot. At a few volcanoes, especially those with domes and extensive fumarolic activity, ash can contain elevated levels of minerals like cristobalite (a form of quartz) that cause silicosis. This would only pose a threat to those with prolonged, unprotected exposure to the ash (http://www.ivhhn.org/). Except for that rather low, long-term risk, ash is no more toxic than ordinary dust. The easiest solution for both is an inexpensive dust mask like those used by painters. These kinds of protective masks are often available in hardware stores or pharmacies. Schools that are expecting ashfall might want to keep a stock of dust masks in storage or require students to bring them from home.

Ash affects many other aspects of everyday life, from water supply to road transportation, and from electrical power lines to computers. It can be an expensive nuisance! More information on ash can be found at http://volcanoes.usgs.gov/ash..

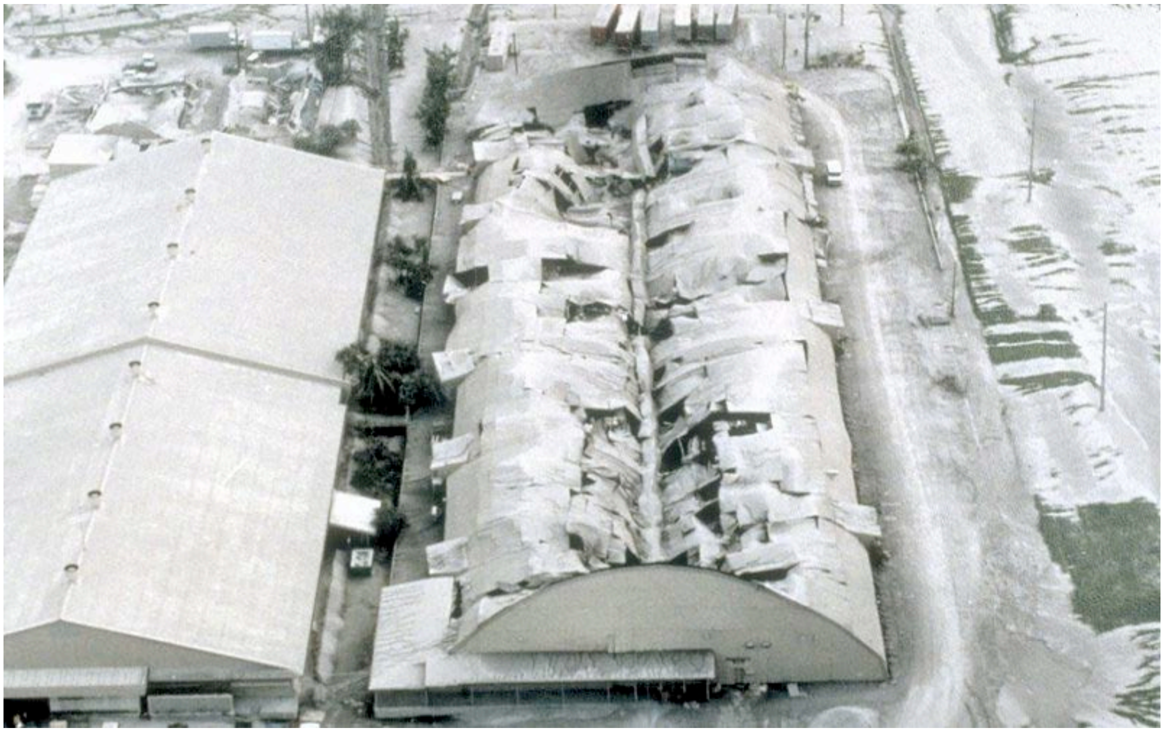


FIGURE 6. COLLAPSED AND UNCOLLAPSED ROOFS AT CLARK AB, PHILIPPINES, AFTER JUNE 1991 ERUPTION OF PINATUBO. PHOTO, USGS

Can Eruptions be Forecast?

Often, but not always.

Why often?

Magma that is rising through the Earth's crust creates quite a few tell-tale geophysical and geochemical signs that reach the surface before the magma itself does. Generally, some rock must be fractured in order for magma to pass, and this fracturing generates small earthquakes. Slightly different varieties of small earthquakes give scientists additional clues about whether and where magma is rising. All of these small earthquakes are recorded on seismographs operated by volcano observatories (figure 7).

As magma rises, gas that is dissolved within the magma will also start to exsolve (form bubbles) that increase internal pressures and cause the slopes of volcanoes to swell slightly, like a balloon. This inflation is detectable using instruments called tiltmeters or precise GPS, and by comparing two successive satellite-based radar images of the volcano (radar interferometry, or InSAR). In addition, some of that gas escapes from the magma and rises to the surface, where it can be measured using spectrometers and other instruments.

Why can eruptions not always be forecast? Fewer than 100 of the world's more than 500 active volcanoes have good monitoring, and only another 200 have any monitoring at all. That leaves approximately 200 active volcanoes with no monitoring, and an additional approximately 1000 "dormant" but potentially active volcanoes with little or no monitoring. Even at volcanoes that are well monitored, eruptions can still occur with little notice, if magma is already close to the surface, doesn't need to fracture rocks, and can't build up much pressure. We call these "open-vent" volcanoes, and precursors to eruptions here are relatively subtle and hard to spot. Fortunately, volcanoes that have been quiet for decades or longer and produce most large eruptions are plugged to one degree or another and thus, generate ample signals before they erupt.

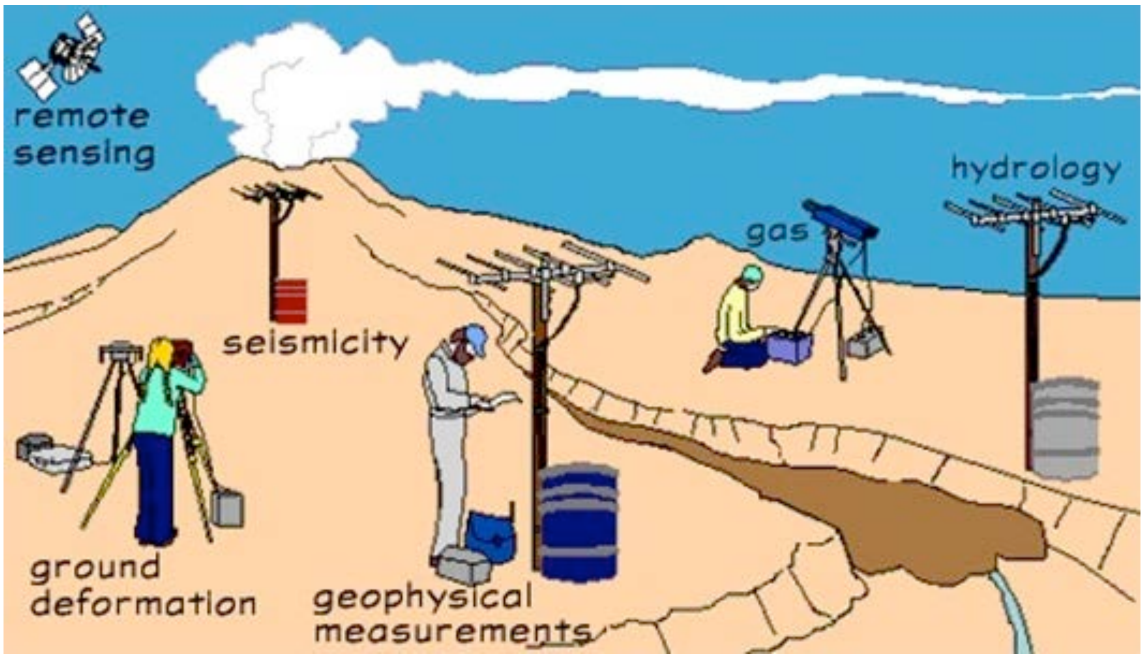


FIGURE 7. VARIOUS WAYS TO MONITOR VOLCANOES AND FORECAST ERUPTIONS. FIGURE BY B. MYERS, USGS.

While it is nice to have ample eruption precursors, a downside is that rising magma may pause *en route* to the surface and doesn't always erupt. Competing forces promote and impede magma from reaching the Earth's surface (figure 8). If magma pauses or stalls *en route*, an earlier forecast of eruption might become a false alarm. Scientists by nature are very conservative and don't like to make forecasts until they are quite sure that an eruption will occur. But this might be too late for an evacuation to take place. The more risk that citizens are willing to accept in order to remain in their homes, the longer that scientists can wait until issuing forecasts, and the more certain those forecasts will be. By contrast, low risk tolerance will require early and very uncertain forecasts. What is really needed is a kind of social contract or compact between volcanologists, officials and citizens. This contract would measure and acknowledge a community's risk tolerance, adjust warnings accordingly, and then expect citizens to accept some risk and to evacuate, if and when evacuation is recommended.

To provide a consistent, easily understandable warning scale, and to reflect the uncertainties of eruption forecasting, many volcano observatories now use 3-5 numerical or color codes of increasing concern or imminence of eruption. The simplest are like traffic lights, with green, yellow, and red. Others add another level or two, e.g., with orange between yellow and red. Whether stated explicitly or not, increasing levels of alert usually imply that an eruption is drawing near or has just begun. In many countries the responses of civil defense are keyed to the coded alert level, with evacuation recommended at the top or next to the top level of alert. Because warning schemes vary from country to country, please refer to your own national scheme.

What Might You Expect in a Typical Volcanic Crisis?

Scenarios of how an eruptive crisis might evolve—from precursors through eruption (if any) to post-eruption lahars and other sediment problems—vary widely. One way to get an idea of the range of scenarios is to read popular books like *The Day the World Ended* by Thomas and Morgan-Witts; *Volcanoes* by Decker and Decker; *Eruptions that Shook the World* by Oppenheimer, and *La Catastrophe* and *Vesuvius, a Biography* by Scarth.

Magma beneath a volcano has competing forces: some are acting to push it upward to eruption, while other forces resist (figure 8). The main factors promoting eruption are high supply of magma and gas from depth, unblocked pathways toward the surface, and a rate of ascent that is fast enough that the magma doesn't degas (literally, run out of gas) before eruption. Resisting factors include the opposite – low supply, physical blockages or anything else that slows magma ascent and gives it time to degas.

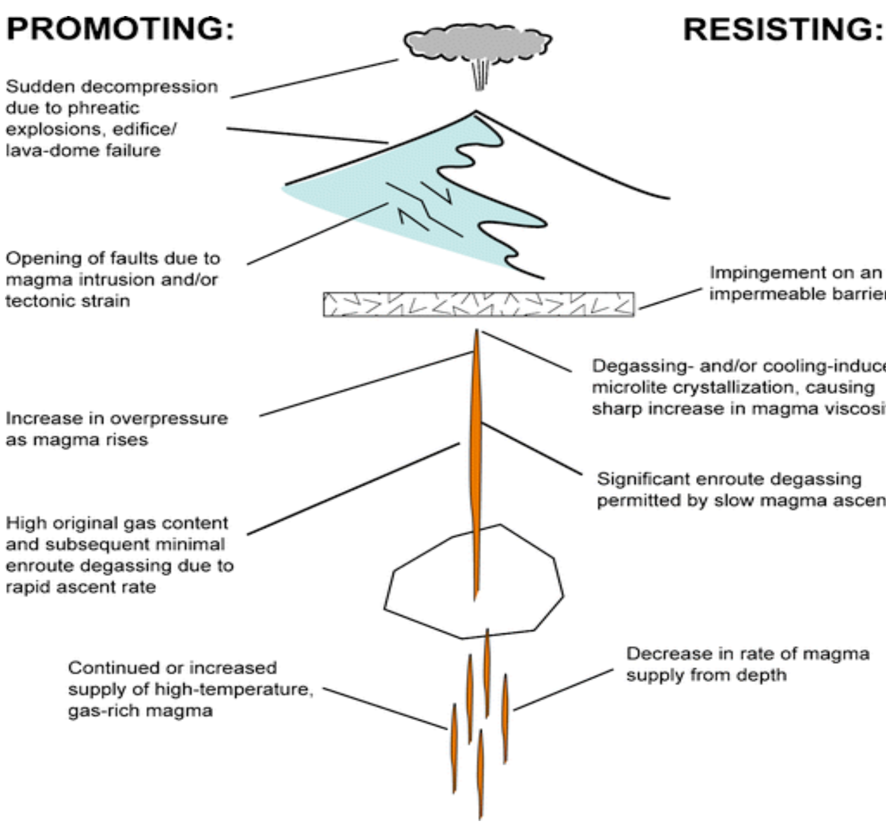


FIGURE 8. FACTORS PROMOTING AND RESISTING (IMPEDING) MAGMA ASCENT AND ERUPTION. FROM MORAN AND OTHERS, 2011.

Nearly all volcanoes give seismic, geodetic, or gas signals in advance of eruptions. These signals are the basis on which scientists can forecast whether and when magma will erupt. Eruptions without known precursors are mostly events in which monitoring was inadequate or non-existent. In this respect, volcanic risk is easier to manage than that from earthquakes, because it is possible to give good short-range warnings in time for people to be evacuated from the most dangerous areas.

That optimistic view must be tempered by some still-serious challenges. Two challenges have already been noted—inadequate monitoring of many volcanoes, and the potential for false alarms. A premature evacuation recommendation can sharply diminish the credibility of scientists and officials and lead the public to mistrust danger warnings. On the other hand, no one wants an evacuation recommendation to arrive too late. Communities need to accept some risk of false alarms, if they want to be safe.

A third challenge is that many volcanoes exhibit a wide range of types and scales of eruptions, from benign ash puffs to enormously dangerous explosive eruptions. Volcanologists are still struggling to distinguish the precursors of small vs. large eruptions, but it seems that they might not be very different. Even big eruptions start out as small ones and then shift into a runaway escalation. In the case of Pinatubo, the final runaway escalation took place in the last 24 hours before the climactic phase. Fortunately, most people had already evacuated. There would not have been time or government help for evacuation during the short time of the final run-up to the eruption. Just as one doesn't want to recommend an evacuation too early or too late, one doesn't want to recommend an evacuation that is too large or too small. Forecasting when unrest will lead to an unusually large explosive eruption is still tricky and relies mainly on a relatively brief, rapidly escalating set of final warning signs from the volcano.

Unlike earthquakes, in which the worst is over within minutes, or tsunamis, tropical cyclones, or floods that have passed within days, threats from volcanoes typically take days to years to ramp up to the onset of an eruption, days to years of eruption itself, and then at least a few years of post-eruption muddy aftermath. Usually, the most hazardous period will be limited to a few weeks, a reasonable duration for evacuation, but forecasting the right weeks in which to evacuate is still a challenge.

Gordon Woo and Warner Marzocchi published interesting papers recently on how to use a cost-benefit analysis of evacuation to decide "scientifically" whether and when to evacuate, and what scale is justified (Woo, 2008; Marzocchi and Woo, 2009). To summarize the papers briefly, they argued that, considering Gross Domestic Product and nominal values of life, the cost of an evacuation can be compared to the expected loss if evacuation is not made. A probability threshold can be calculated, above which evacuations are warranted. Evacuations are often warranted even if probabilities of eruption are less than 0.1 (10%). The same principles can be applied to any hazard and evacuation decision.

Woo and Marzocchi did not break the decision down into elements of a community, such as schools, but one could do so. In most countries, teachers are respected, educated, and expected to spot problems before others and to set a good, safe example. Parents are also worried that they might be separated from their children, so a decision to suspend classes might precede a decision for community evacuation.

International Assistance

Most countries will prefer to handle volcanic crises by themselves, but, when their own capacity is exceeded, they will invite foreign colleagues to help. The most established crisis assistance program is the Volcanic Disaster Assistance Program (VDAP) of the US Geological Survey, co-funded by USAID. This team has experienced staff and a store of equipment at the ready, to help upon invitation from a host country needing extra support. Other teams are available through Japan's JICA, France's IRD, and UK's DFID.

Education ministries, civil defense, and other government bodies that are concerned about a developing volcanic crisis sometimes call directly for international volcanological help. However, it is almost always better to work through your local volcanology agency or through an officially mandated volcano team from a local university. An invitation to foreigners that bypasses local scientists can lead to awkwardness or even to infighting, and the enormous challenges of volcanic crises require that all scientists be helping, rather than competing with, each other. Only the local volcanological agency knows best what help it needs and how best to coordinate offers of help from multiple scientists and countries. The USGS' VDAP accepts invitations or requests for help from local volcanologists, made through USAID or through the US Embassy, where USAID is not present. Contact information for your local volcano observatories may be found at www.wovo.org, or by direct linking to those observatories.

Disruption of Schooling

Evacuations disrupt schooling. Evacuated children need new classrooms, which during an emergency might be anything from chairs beneath a tree or tent to portable classrooms brought into evacuation centers. If evacuees are housed in schools outside the danger zone, as is often the case, then classes for students of those "safe" schools will also be disrupted. A few days of disruption are normal in any school year, but if the disruption continues for months, then schooling suffers. Solutions can include shifting to split or double sessions, or comprehensive relocation of disrupted communities.

An effect of such disruptions that is often unnoticed but can be quite severe in lower income economies is that student dropout rates will increase. The children may be required to supplement the family income, or the parents may be frightened and want to keep the children close at hand. Perhaps the most common reason for dropouts is that parents can no longer afford even modest school costs (uniforms, supplies, transportation), much less full tuition costs.

Living with Volcanic Risk

Given the infrequency of volcanic eruptions, compared to floods, tropical cyclones, and other hazards; the likelihood of advance warning; and the fact that quiet volcanoes are picturesque and fertile, most people who live near volcanoes will choose to remain in their homes unless ordered to evacuate. Well-timed evacuations of several weeks are usually enough to get past the worst of the danger. Considering volcanic hazards when siting schools may help to avoid later problems, but as with all policy decisions, the costs of siting in a safe area need to be compared to the costs of not adopting this precaution. If a school is sited in a hazardous area, then paying close attention to temporary evacuation recommendations will ensure reasonable safety for students, teachers and staff. In making contingency plans, officials should plan for a period of disruption that lasts for weeks or longer for students both in and near threatened areas.

Teacher's Resources

To help teachers meet community and government expectations to teach about volcanoes, a number of educational resources are available. Most are available on the web; a few require purchase of DVD's or similar resources.

One helpful starting point is the United States Geological Survey's webpages from the Volcano Hazards Program, http://volcanoes.usgs.gov. This includes "Volcano Resources for Educators", at http://volcanoes.usgs.gov/about/edu/index.php.

In turn, the Educators' page points to "Alaska Volcanoes Guidebook for Teachers" http://pubs.usgs.gov/gip/99/ (Adelman, USGS General Info Product 99), "Living with a Volcano in your Backyard – An Educator's Guide with emphasis on Mount Rainier" http://vulcan.wr.usgs.gov/Outreach/Publications/GIP19/framework.html (Driedger, Doherty, and Dixon, 2005, USGS GIP 19), and a number of other resources. Effects of ashfall on communities and people are detailed a http://volcanoes.usgs.gov/ash and at http://www.ivhhn.org.

Video clips of selected volcano and earthquake topics, including Mount Pinatubo, may be found on the Teachers' Domain website, e.g., at http://www.teachersdomain.org/asset/ess05_vid_lahar/.

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Part Three: Appendices

Self-Assessment Protocol

School Safety in Earthquakes, Tsunamis and Volcanic Events

Purpose

The purpose of this assessment "protocol" is to help you evaluate the policies, programs and practices currently followed in your jurisdiction regarding educating students about natural hazards, constructing and maintaining buildings, and preparing for natural hazard events. The safety of students depends on a number of factors—understanding of natural hazards; the state of school buildings, grounds and building contents; and the existence, and public awareness, of preparedness plans. Each factor, taken alone, can improve student safety, but *all* of these factors should be addressed.

Safety from natural hazards is a continuing concern, and providing safe schools for students requires a sustained effort. Each year, students should learn more about the science and effects of natural hazards. Each year, preparedness plans should be reviewed with students and practiced through drills. Each year, student release policies that control where students would be sheltered and to whom students would be released after a hazard event should be updated in consultation with parents or guardians. Buildings should be surveyed annually, and tall and heavy items of furniture, equipment, or science lab supplies should be properly anchored or stored. School buildings and sites should be evaluated after new hazard maps are prepared and after each time that building codes change significantly.

This assessment protocol allows you to determine whether or not your jurisdiction currently complies with the principles and carries out the activities identified as important in the *Safe@School—Protecting Children from Natural Hazards* framework. That framework was endorsed by participants in the October 2011 workshop, "School Earthquake and Tsunami Safety in APEC Economies: Reducing Risks and Improving Preparedness." Any shortcomings in your existing program that you identify provide the basis for a work plan to identify new measures that should be implemented. School officials should discuss potential shortcomings with government agencies responsible for earth sciences and engineering, academic institutions in their country. GeoHazards International will attempt to make helpful referrals following inquiries to info@geohaz.org.

The *Safe@School—Protecting Children from Natural Hazards* framework has four principles and eight activities.

Principles

A. Every child has a right to attend school in safe buildings.

B. Governments and education leaders are responsible to mobilize all effort to ensure the safety of schoolchildren from natural hazards. This requires a strong commitment to sustained action: implementing an effective school safety program is a long-term undertaking.

C. To fulfill their responsibility to ensure the safety of schoolchildren, governments and education leaders must
   1. Identify responsible agencies and officials in the government and private sectors;
   2. Define expectations regarding their roles in a school safety program;
   3. Identify funding sources for their work;
   4. Identify hazard areas and vulnerable buildings;
   5. Identify necessary education and preparedness activities;
   6. Measure progress on reducing risk;
   7. Report to higher authorities, parents and teachers on items.

D. An effective school safety program will
   1. Stipulate the desired safety performance for school buildings and construct all new schools to meet this standard;
   2. Educate students on natural hazards and risk reduction measures;
   3. Provide preparedness training;
   4. Review conditions of all existing school buildings and retrofit, relocate or replace unacceptably vulnerable buildings;
   5. Draft and enact plans for post-event continuity of education services.

Activities

Activities are programs or practices that carry out the principles embodied in the policy statement. They are the essential ingredients of an effort to ensure student safety during hazard events.

1. **Identify and map hazards nationwide and in detail at every school site** in order to define the frequency and intensity of natural hazards and the level of potential impacts on students and schools. Consult the hazard maps before constructing new buildings or expanding existing buildings, and incorporate measures into building design, preparedness efforts, and risk reduction programs to reduce the hazard threat;

2. **Prepare a long-term risk reduction plan** that identifies school buildings that do not meet performance standards because of structural weakness or site-specific hazards, and implement the risk reduction plan by retrofitting, replacing or relocating dangerous school buildings;

3. **Identify an organization to implement or oversee the plan** and its elements. This organization would:
   - Identify those responsible for every activity, measure their performance and report results;
   - Approve the location of new schools with regards to natural hazards;
   - Review construction drawings for compliance with building codes;

- Inspect construction to ensure that builders follow the approved plans and specifications;
- Approve evaluations of existing school buildings and locations, and keep records on the condition of deficient buildings.

4. **Adopt and enforce a building code** that includes stringent building standards and enforcement requirements for school buildings;

5. **Establish standards for professional practice and provide a training program** to ensure that the professionals who analyze potential sites and who design and construct school facilities are properly qualified;

6. **Conduct a preparedness program in every school** to ensure that emergency and evacuation plans are prepared with consideration of the hazard conditions of each school, that training sessions and exercises are held regularly, and that
   - Warning and communications systems are in place and maintained to enable communication before and during emergency situations, and warnings of impending hazards (secondary earthquake waves, tsunamis, floods, debris flows) are transmitted effectively and on time;
   - Building furnishings, equipment, contents and decorative building elements that can fall on students or impede evacuation are properly anchored;
   - Community awareness campaigns engage families and the community in risk reduction and preparedness activities (This is a critical complement to school-based programs, as children are in school only 25% of the time.);

7. **Ensure that the curriculum followed in schools educates students** on natural hazards and measures to prepare and respond to hazard events;

8. **Appoint an independent advisory committee** to provide expert advice on implementation and provide oversight on the quality and consistency of risk reduction efforts.

Completing the Form

No single person or organization will have all of the information required to complete this assessment. Respond to each question as best you can, seeking input from knowledgeable colleagues. Depending on the amount of information you need to acquire from others, it may take several weeks for you to complete an assessment.

Part 1. Basic Information

The purpose of this section is to provide basic information about you and your education system.

1. Geographic Area covered by this assessment:

   ____

2. Name of the person(s) completing the assessment:

   ____

   a. Office/Affiliation:

      ____

   b. Email address: ________________________________

   c. Phone number: ________________________________

   d. Mailing address:

      ____

      ____

      ____

3. How many school-age children are enrolled in the schools covered by this assessment?

   a. Total number of children: ____________

   b. Number of children in the following grades:

      i. Grade/class Kindergarten through 5: ____________

      ii. Grade/class 6 through 8: ____________

      iii. Grade/class 9 through 10: ____________

      iv. Grade/class 11 through 12: ____________

4. How many teachers work in schools covered by this assessment? ____________

5. How many schools are covered by this assessment? ____________

6. How many distinct buildings are covered by this assessment? ___________

7. How many schools are owned and operated by the government? ___________

8. Will your schools be used as emergency operations centers or shelters following natural hazard events? (Yes or No) ___________

Part 2. School natural hazard safety policy: institutional structure, legal framework and accountability

The purpose of this section is to describe 1) existing laws regarding natural hazards and school safety, 2) the public bodies and programs established to implement these laws, and 3) the requirements or practices followed to report information regarding natural hazards and school safety to higher authorities, school administrators, teachers and parents.

Institutional structure and legal framework

11. Provide the name, citation and brief description of any laws and public policies intended to ensure the safety of schoolchildren during natural hazard events:

    a. Title of the law or public policy:

    ____

    Citation:

    ____

    b. Title of the law or public policy:

    ____

    Citation:

    ____

    c. Title of the law or public policy:

    ____

    Citation:

    ____

12. Describe the principal stated objectives of these laws and policies regarding the safety of students and the acceptable amount of damage to school facilities caused by an earthquake:

a. ______________________________

____

____

b. ______________________________

____

____

c. ______________________________

____

____

13. List the government agency(ies) responsible for implementing such policy(ies):

a. Agency:

____

Lead Person:

____

Contact Information:

____

____

b. Agency:

____

Lead Person:

____

Contact Information:

____

____

c. Agency:

____

Lead Person:

____

Contact Information:

____

____

14. Provide the name, agency or office, and contact information for the lead person responsible for the safety of school children in natural hazard events.

Agency or office:

____

Lead Person:

____

Contact Information:

____

____

____

____

Accountability

The purpose of this section is to identify the persons responsible for decisions that affect the safety of students in schools during hazard events, and to how this information on safety is shared.

15. List the names of the organizations and officers who are responsible for the following decisions:

a. Planning, designing, constructing and financing school buildings

Agency:

____

Lead Person:

____

b. Contact Information:

____

____

c. Selecting building sites

Agency:

Lead Person:

Contact Information:

d. Designing buildings for construction or alterations

Agency:

Lead Person:

Contact Information:

e. Construction of buildings and other school facilities:

Agency:

Lead Person:

Contact Information:

f. Maintaining school buildings

Agency:

____

Lead Person:

____

Contact Information:

____

____

16. Who is responsible for the following activities:

a. Overseeing, reviewing and approving planning, design and construction decisions

____

b. Approving building sites relative to hazardous conditions such as active fault traces, tsunami run up zones and volcanic hazards

____

c. Reviewing and approving design plans and construction documents

____

d. Inspecting construction and certifying conformance with design drawings

____

e. Testing and approving building materials

____

f. Qualifying personnel for design, plan review, construction inspection and materials testing

____

17. Give the location and contact information for the office where the results of these evaluations are kept.

____

____

____

18. Describe how the information collected by these evaluations is reported to higher officials, parents and the public.

____

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____

____

Part 3. Hazard identification and site analysis and selection

The purpose of this section is to determine if the hazards that affect school sites are identified and if the information is used to locate new buildings properly, to evaluate the safety of existing buildings, to prepare emergency plans, and to train students.

17. Give the title of appropriate scale (~1:2,000) maps available that identify the following hazards:

Earthquake shaking intensity:

____

Earthquake fault location:

____

Landslide prone areas:

____

Liquefaction prone areas:

____

Tsunami inundation areas:

____

Flood inundation areas below dams or glacial lakes:

____

Volcanic debris flow areas:

____

Volcanic blast areas:

____

Other hazardous areas:

____

18. When adequate maps are not available, do the responsible agencies consult with experienced professionals (geologists, hydrologists, tsunami engineers and volcanologists) for information regarding the hazard conditions at school sites? (Yes or No) _________________________

19. Describe the experienced professionals who provide this information:

____

____

____

____

____

Part 4. Building codes and code enforcement

The purpose of this section is to determine whether or not your building codes address the hazards that affect your schools and whether or not they are up to date with current information and reliably followed.

Building Codes

20. Cite the title and latest adoption date for building codes that control the design and construction of school buildings for the following hazards:

Earthquake Shaking:

____

Date adopted: ____________________

21. High wind velocity:

____

Date adopted: ____________________

Tsunami run up:

____

Date adopted: ____________________

Fire:

____

Date adopted: ____________________

22. Do the building codes include provisions that respond to information on the hazard maps? (Yes or No) ________

23. Do building codes or other laws impose special requirements for the site conditions?

Mark "Y" next to <u>all</u> that apply:

____ Soil conditions (e.g., soft soil, high ground water, rock)

____ Tsunami inundation zones

____ Flood zones or sites subject to flooding from dam breach or glacial lake outburst

____ Landslide zones

____ Wind velocity

____ Other hazards (please describe)

Code Enforcement

24. Does the entity responsible for the schools covered by this evaluation consistently require that the building code be followed for the design of all school buildings under its control? (Yes or No) ________

25. Does the responsible entity use any of the following processes to ensure enforcement of school building codes? ***Mark "Y" next to <u>all</u> that apply:***

____ Independent* review and checking of building design/construction plans
____ Independent** inspection of construction work to assure builders follow the plans and the materials (concrete and reinforcing steel) meet appropriate standards

____ Certification that school building design meets standards
____ Certification that school building construction meets standards

*Independent means that the reviewers do not work for and are not paid by the engineer or architect responsible for the designing the building.

**Independent means that the construction inspectors do not work for and are not paid by the construction company.

26. Does the responsible entity arrange for an independent review by peers of professional decisions regarding hazards, design criteria, assumptions and analytical methods used in the selection of sites, design of buildings or analysis and retrofitting of existing buildings? (Yes or No) ________

27. If Yes, then describe the procedures that provide for peer review.

____

____

____

____

____

Many of the decisions made by professionals regarding conditions that affect safety, such as delineating inundation zone boundaries, identifying potential rock falls or determining the earthquake strength of buildings require professional judgement, as well as expert analysis. Experience has demonstrated that these decisions are improved and made more consistent through a process called “peer review,” whereby qualified experts review work performed by their peers to ensure that it meets specific criteria. The process is “equals helping equals;” it is not adversarial.

A peer review process will improve school safety, consistency in how codes and requirements are applied, and can also reduce costs. However, to be effective, peer reviewers should have experience, knowledge and skills as good as or better than the minimum qualifications of those doing the design. Reviewers should be independent of the building owner, design professional (architect or engineer) and contractor financially, by agency reporting links, and/or by family relationships. They should not be responsible for the design or report to those who are responsible; they should not be responsible for complying with a project budget or deadline(s); and ideally, they should report to an organization that is solely responsible for code enforcement. Independence ensures that the reviewer is not under pressure from those who have a stake in the project and that the process is transparent.

Part 5. Professional training and qualifications

Many jurisdictions enforce training, certification and licensing procedures for professionals involved in the design and construction of school buildings, and in the evaluation of the design and control of construction quality.

The purpose of this section is to describe the measures taken to ensure that the professionals responsible for the design and construction of school buildings are qualified to prepare architectural drawings that result in safe buildings and to evaluate existing school buildings constructed according to standards of earlier building codes (or without codes), in order to determine whether or not the buildings can reasonably resist natural hazards, and whether the professionals can strengthen the schools.

28. Provide the name of the government agency or professional society that evaluates and certifies the qualifications of the following people who are responsible for building design and enforcing building codes.

    a. Architects:

    ____

    b. Engineers:

    ____

    c. Plan checkers (officials who review construction plans for code compliance):

    ____

    d. Construction inspectors (those who inspect construction at the job site to ensure it conforms to the design drawings):

    ____

Part 6. Preparedness and planning

The purpose of this section is to describe the preparedness of schools and communities in terms of school emergency planning, post-earthquake damage assessment and drills.

26. Is the information on hazard maps used to decide upon the nature and extent of hazards affecting school sites for emergency planning and training?

Always _________
Sometimes _________
Never _________

27. Describe your program to prepare students, teachers and administrators to respond properly during and after hazard events. Provide the program name, responsible agency, and responsible person with contact information.

____

____

____

28. Describe requirements for school emergency plans and the actions, decisions and responsibilities needed before, during and following an earthquake, tsunami or volcanic event:

____

____

____

____

29. Describe the frequency of drills to simulate **natural hazard** events or warnings of event.

a. Fire drills: ____________________
b. Earthquake drills: ____________________
c. Tsunami evacuation drills: ____________________
d. Flash flood/pyroclastic and mud flow drills: ____________________

30. Describe any warning systems in place that are used to alert school site administrators and students of unsafe conditions such as warnings of tsunamis, dam failures, volcanic debris flows and other hazards such as landslides, flash floods, cyclones and wildfires:

____

____

____

____

31. Describe how emergency plans address school building evacuation and/or re-occupancy decisions during and after hazard events?

a. Tsunami evacuation:

____

____

____

b. Flood evacuation:

____

____

____

c. Post earthquake:

____

____

____

d. Other hazards:

____

____

____

32. Describe requirements for evacuation plans that identify routes to take and the location of safe areas in case of warnings or occurrence of the following events:

a. Tsunami:

____

____

____

b. Floods due to high flows or dam failure:

____

____

____

c. Volcanic activity:

____

____

____

33. Describe your student release policy governing how students will be held at school and released to appropriate family members or adults following a hazard event.

____

____

____

Part 7. Risk reduction in new and existing educational facilities

The purpose of this section is to describe measures school officials take to reduce risk in vulnerable existing school buildings.

34. Is the information on hazard maps used to evaluate the safety of existing school buildings?
Always ______
Sometimes _________
Never __________

35. Building codes and construction practices typically improve as new scientific and engineering information becomes available. Existing buildings built using older versions of the codes or hazard maps may not be safe. Describe programs to identify and assess schools built using older versions of the building code or hazard maps for potential vulnerabilities to natural hazards:

____

____

____

____

36. Describe any long-term risk reduction programs to retrofit, replace or relocate existing school buildings found to be vulnerable to earthquake shaking and ground failure, volcanic debris flows, flooding from rivers, tsunamis and cyclones:

____

____

____

____

a. Does the program have qualified people? (Yes or No) __________
b. Does the program have funds to implement the work? (Yes or No) __________
c. Do you have retrofit, replacement or relocation guidelines to follow? (Yes or No) __________
d. Do you have a process for setting priorities to determine the order in which buildings are dealt with? (Yes or No) __________
e. Describe the program name, and give the name of the responsible person for each hazard:

____

____

____

____

37. Does the technical expertise for the seismic retrofit of buildings exist within government agencies and/or can it be obtained from engineers in private practice? (Yes or No) __________

38. Do you periodically assess school buildings to identify dangerous conditions such as falling contents (book shelves, laboratory equipment, storage cabinets, etc.)? (Yes or No) __________

39. Describe measures taken by schools to reduce risks from falling contents (such as bookshelves, laboratory equipment, and storage cabinets):

____

____

____

Links to Relevant Websites or Online Material

ORGANIZATIONS

GeoHazards International (http://www.geohaz.org/)

National Science and Technology Center for Disaster Reduction (*NCDR*) (http://www.ncdr.nat.gov.tw/English/)

Earth Observatory of Singapore (http://www.earthobservatory.sg/)

International Tsunami Information Center (http://itic.ioc-unesco.org/)

US Geological Survey (http://www.usgs.gov/)

Cascades Volcano Observatory (CVO) (http://vulcan.wr.usgs.gov/)

INFORMATIONAL RESOURCES

USGS webpage on natural hazards (http://www.usgs.gov/natural_hazards/)

EARTHQUAKES

California Watch, *On Shaky Ground*, investigating construction standards for public schools (http://californiawatch.org/earthquakes/)

Federal Emergency Management Agency, 2003, NEHRP Recommended Provisions: Instructional and Training Materials: FEMA 451B, Topic 5A, Seismic Hazard Analysis (http://www.nibs.org/index.php/bssc/publications/2003/fema451btraining/
USGS Pager (Prompt Assessment of Global Earthquakes for Response) system
http://earthquake.usgs.gov/earthquakes/pager/)

TSUNAMIS

Designing for Tsunamis (http://www.oregonvos.net/~rbayer/lincoln/ec-misc.htm)

Sample K-6 Tsunami Curriculum
(http://ioc3.unesco.org/itic/files/tsunami_curriculum_K_6.pdf)

VOLCANOES

USGS Volcano Hazards Program (http://volcanoes.usgs.gov/)

Volcano Resources for Educators (http://volcanoes.usgs.gov/about/edu/index.php.)

APEC Workshop Participant Questionnaire

SCHOOL SAFETY IN EARTHQUAKES, TSUNAMIS, VOLCANIC ERUPTIONS AND FLOWS

Purpose

The purpose of this questionnaire is to describe the characteristics of policies in your economy, relating to the elements and principles of an effective school safety program for natural hazards.

Completed questionnaires will be used for a project of Asia Pacific Economic Cooperation (APEC) regarding the safety of schools during natural hazard events such as earthquakes, tsunamis and volcanic activity. Representatives of APEC member economies will meet with school safety officials and experts on natural hazards to discuss policies that provide safe schools at a workshop in Chinese Taipei on October 17 - 19, 2011. A representative of your economy will have the opportunity to present the results from your questionnaire at the workshop.

Completing the Questionnaire

No single organization, ministry, department or other group will have all of the information required to complete the questionnaire. You will need to collect information from other relevant ministries, agencies, departments and groups. Depending on the amount of information that you need to acquire from sources outside your agency or organization, it may take several weeks for you to complete the questionnaire.

You can complete the questionnaire either by typing in this electronic file, or by writing on a hard copy – whichever is more convenient for you. If you need more space, please simply expand the space given in the questionnaire (for electronic copies) or attach additional pages (for hard copies).

General guidelines

Please consider the following general guidelines when completing the questionnaire:

- For open-ended questions, provide brief responses between 100 and 200 words.
- Provide data, statistics and other supporting evidence, where possible.
- Use case studies and provide historical context, where appropriate.
- Reference national legislation and regulations.
- Complete as much of the questionnaire as you can, even if you are unable to obtain answers to some of the questions.

Acknowledgments

This questionnaire is based on a school earthquake safety self-assessment questionnaire developed by the Organisation for Economic Co-operation and Development (OECD), in collaboration with GeoHazards International (GHI).

Part 1. Basic Information

The purpose of this section is to provide basic information about your country's education system.

1. How many years of school education are compulsory? ______

2. How many school-age children are in your country?

    a. Total number of children _____

    b. Number of children in the following grades:

        i. Grade/class Kindergarten through 5 ___________

        ii. Grade/class 6 through 8 ___________

        iii. Grade/class 9 through 10 ___________

        iv. Grade/class 11 through 12 ___________

3. How many teachers in your country? ___________________

4. How many primary and secondary schools are there in your country? ______________________

5. How many schools are owned and operated by government bodies such as cities, states or provinces or the national government? __________________

6. How many schools are owned and operated by non-governmental groups such as NGOs, or religious organisations? _____________________

7. How many schools are owned and operated by private, for-profit companies? _____________

8. How many schools are owned and operated by the families in the community? ____________

9. Do government standards for curriculum and student performance apply to non-governmental schools? ***Yes (Y) or No (N)*** ____

10. Does your country use schools for emergency operations centers or shelters following natural hazard events? ***Yes (Y) or No (N)*** ____

Part 2. Natural Hazards

The purpose of this section is to describe information available on natural hazards.

11. How frequently do the following natural hazards affect your country?
Mark "Y" next to all of the hazards that affect your country and estimate the frequency that damaging hazard events occur by marking a circle around the closest time estimate. For example, if damaging earthquakes occurred four times in the last 50 years, circle "Every 10 years":

____ Earthquakes Yearly, Every 10 years, Every 50 years, Rarely
____ Tsunamis Yearly, Every 10 years, Every 50 years, Rarely
____ Cyclones Yearly, Every 10 years, Every 50 years, Rarely
____ Droughts Yearly, Every 10 years, Every 50 years, Rarely
____ Dam failure Yearly, Every 10 years, Every 50 years, Rarely
____ Glacial lake outburst floods Yearly, Every 10 years, Every 50 years, Rarely
____ River floods Yearly, Every 10 years, Every 50 years, Rarely
____ Volcanic eruptions Yearly, Every 10 years, Every 50 years, Rarely
____ Debris flows from volcanoes Yearly, Every 10 years, Every 50 years, Rarely
____ Wildfires Yearly, Every 10 years, Every 50 years, Rarely
____ Other hazards (Please describe and describe frequency of occurrence):

12. Does your country have maps depicting variations in expected natural hazard risks for the following events?

Mark "Y" next to all that apply and fill in year last updated. Scale means the length measured on the map relative to the distance on the ground (e.g., 1 cm= 10 km or 1:100,000):

____ Ground shaking intensity Year last updated ________ Scale________
____ Surface fault rupture Year last updated ________ Scale________
____ Landslides Year last updated ________ Scale________
____ Liquefaction Year last updated ________ Scale________
____ Tsunami inundation Year last updated ________ Scale________
____ Flooding (dam failure) Year last updated ________ Scale________
____ Volcanic blast Year last updated ________ Scale________
____ Volcanic debris flow Year last updated ________ Scale________
____ Other Year last updated ________ Scale________

13. Are these maps used when selecting a site for a new school? ***Yes (Y) or No (N)*** ____
If No, how are hazards considered when selecting the site for a new school?

Part 3. School Natural Hazard Safety Policy: Institutional Structure and Legal Framework

The purpose of this section is to describe existing legislation and public bodies and programs established to support and implement a school earthquake safety program.

14. Does your country have policy (ies) or legislation that acknowledges the need to ensure the safety of schoolchildren during a natural hazard event?
Yes (Y) or No (N) ____

If yes, *please describe the legislation or document, its name and objectives.*

15. If you have such policies, does your country designate specific government agency (ies) or local/regional authorities to work on implementing such policy (ies)?
Yes (Y) or No (N) ____

If Yes, please describe geographical jurisdiction of the agency (ies); and strategies for achieving the policy objectives.

16. Does the agency(ies) in Question 15 have a clearly identified set of priorities for identifying schools and buildings most in need of help to make their schools safer?
Yes (Y) or No (N) ____ ***or Not applicable (N/A)*** ____

If Yes, please describe the criteria used to establish these priorities.

17. Does your country have a program(s) guiding earthquake, tsunami or volcanic hazard risk reduction in schools?
Yes (Y) or No (N) ____

If Yes, please briefly describe the program(s), providing information on program mission, duration, structure, reporting mechanisms, number of staff and budget.

Part 4. Accountability

The purpose of this section is to explore elements of accountability that affect school earthquake safety programs.

18. Is there an agency(ies) or mechanism responsible for planning, designing, constructing and financing school buildings–for overseeing and approving site selection and proper planning, design, construction and maintenance of school buildings? ***Yes (Y) or No (N)*** ____

If yes, *is the agency(ies) or mechanism independent of the agency(ies) funding, designing and building the school buildings?*

If there is an agency(ies) or mechanism**,** please mark the tasks it carries out.

Mark "Y" next to all that apply:

____ Approving the site relative to hazardous conditions such as active fault traces, tsunami run up zones and volcanic hazards
____ Reviewing and approving design plans and construction documents
____ Inspecting and approving construction
____ Qualifying personnel for design, plan review, construction inspection and materials testing
____ Conducting assessments of school building conditions
____ Reviewing and approving budgets or expenditures
____ Other (please describe):

19. In addition to the agency(ies) described in Question 18, please list the roles and responsibilities of other participants (*i.e.,* individuals, agencies, organisations and province/state and local administrative groups) involved in school earthquake safety.

Part 5. Building codes and code enforcement

The purpose of this section is to explore the objectives and performance criteria of existing school building codes, and the responsible agency's capacity for review and enforcement of these codes.

20. Does your country, either national government or sub-national government (states, regions, districts, etc.) have a building code for the design and construction of school buildings to resist the effects of the following hazards?
Mark Yes (Y) or No (N)
____ Earthquake Shaking
____ High wind velocity
____ Tsunami run up
____ Fire

21. Which agency(ies) is responsible for writing the building code?

22. Is following the building code mandatory for the design of government school buildings in all areas of the country?
Yes (Y) or No (N) _____

If No, please identify in which locations/jurisdictions the building code is mandatory, if any:

23. Do building codes and construction practices apply to non-governmental schools?
Yes (Y) or No (N) _____

24. Is there a process to ensure enforcement of school building codes?

Mark "Y" next to all that apply:
____ Independent* review and checking of building design and construction plans
____ Independent** inspection of construction work to assure builders follow the plans and the materials (concrete and reinforcing steel) meet appropriate standards
____ Certification that school building design meets standards
____ Certification that school building construction meets standards

*Independent means that the reviewers do not work for and are not paid by the engineer or architect responsible for the designing the building.
**Independent means that the construction inspectors do not work for and are not paid by the construction company.

For all items marked above, please describe these processes, addressing in particular provisions made for the verification of design plans for school buildings by independent qualified reviewers, and for the inspection and certification of constructed school facilities. Please describe capacity of the national administration to perform duties related to building code enforcement (*i.e.,* how many staff members are assigned to these duties; what are their tasks, responsibilities, qualifications and workload?).

25. Which of the following best describes the safety objectives of school building codes for new buildings? (Note: a number of building codes state the intent of the code, in terms of safety, in the introductory sections.)
Mark "Y" next to one:
____ Prevent collapse of school buildings so students can safely get out
____ Minimise damage to allow rapid occupancy of buildings after earthquakes
____ Prevent damage so the building can be used immediately following an earthquake
____ Don't know / unsure
____ Other (please describe):

26. Are the safety objectives of school building codes for new school buildings the same for strengthening existing school buildings?

Yes (Y) or No (N) _____

If No, please explain how the safety objectives differ:

27. Do building codes or other laws impose special requirements for the site conditions?
Mark "Y" next to <u>all</u> that apply:
____ Soil conditions (e.g., soft soil, high ground water, rock)
____ Tsunami inundation zones
____ Flood zones or sites subject to flooding from dam breach or glacial lake outburst
____ Landslide zones
____ Wind velocity
____ Other hazards—(please describe)

28. Is there a process for periodic review and revision of school building codes?
Yes (Y) or No (N) _____

If Yes, please describe how frequently these reviews take place and how the reviews are conducted. *If codes are not reviewed on a regular basis*, please describe when and on what basis a code(s) was reviewed and revised. Please give the years of the last two revisions of the building code.

Part 6. Professional training and qualifications

The purpose of this section is to understand the level of formal qualification, training, certification and licensing procedures for professionals involved in the design and construction of school buildings.

29. Does a government agency or professional society evaluate the qualifications of the people responsible for applying (engineers and architects) and/or enforcing building codes (plan checkers or construction inspectors) and then issue a license or certificate to recognize their qualifications?
Mark "Y" next to <u>all</u> that apply:
____ Architects
____ Engineers
____ Plan checkers (officials who review construction plans for code compliance)
____ Inspectors (those who inspect construction at the job site to ensure it conforms to the building code)

For each Yes, please describe the nature of certification/licensing and the certifying/licensing body.

30. Is **knowledge** of how to resist earthquakes, tsunamis, strong wind or volcanic forces through design and construction a qualification requirement for professionals engaged in the planning, design and construction of school facilities?

Mark "Y" next to all that apply:
____ Architects
____ Engineers
____ Construction contractors / builders
____ Plan checkers (officials who review construction plans for code compliance)
____ Inspectors (those who inspect construction at the job site to ensure it conforms to the building code)

If Yes, please describe qualification requirements for each category of professional.

Part 7. Preparedness and planning

The purpose of this section is to explore the preparedness of schools and communities in terms of school emergency planning, post-earthquake assessment and drills.

31. Are schools required to have an emergency plan that specifies the actions, decisions and responsibilities needed before, during and following an earthquake, a tsunami or volcanic event?
Yes (Y) or No (N) _____

If Yes, please describe the nature of the emergency plan and the agency(ies) responsible for implementing the plan and allocating resources.

32. Are schools required to hold periodic drills to simulate **natural hazard** events or warnings of event?
Yes (Y) or No (N) _____

If Yes, please describe the nature and frequency of the drills.

If drills are not held periodically, on what basis have drills been performed in the past?

33. Are schools required to hold periodic **fire** drills?
***Yes (Y) or No (N)* _____**

If Yes, please describe the nature and frequency of the drills.

If drills are not held periodically, on what basis have drills been performed in the past?

34. Following a natural hazard event, who or what agency is responsible for making decisions concerning the evacuation and re-occupancy of school buildings?

35. Do schools have evacuation plans that identify routes to take and the location of safe areas in the event of the following events?
Mark "Y" next to all that apply:
____ Tsunami warning
____ Dam failure
____ Volcanic activity

36. Is there a student release policy determining how students will be held at school and released to appropriate family members or adults following a hazard event?
***Yes (Y) or No (N)* _____**

37. Following a natural hazard event, how is information on the status of schools disseminated to the public?
Mark "Y" next to all that apply:
____ Television
____ Radio
____ SMS / Text message
____ Internet (including social media)
____ In person
____ Other (please describe):

Part 8. Community awareness and participation

The purpose of this section is to explore the capacity of the national administration to perform duties related to improving community awareness and participation.

38. What formal and informal communication tools exist to disseminate information related to policies, programs and responsibilities for school natural hazard safety to school communities and other groups?

39. Are there community-based programs or initiatives that seek to raise awareness and knowledge of risk from natural hazards?
Yes (Y) or No (N) _____

If Yes, please provide information on the program content, objectives, people involved and duration for **two (2)** of these programs.

Part 9. School curriculum

The purpose of this section is to understand educational programs and materials on natural hazards and risk reducing activities.

40. Have issues such as natural hazard safety awareness and preparedness been incorporated into the curriculum across different levels of education and subject areas?
Yes (Y) or No (N) _____

If Yes, please describe the curriculum content, audience, subject area in which the natural hazard material is taught and year introduced, and whether the information is covered again in later grades.

41. At what grade are students taught about plate tectonics, earthquakes, tsunamis or volcanic events?

42. Does the curriculum include discussion of historic earthquakes, tsunamis or volcanic events that affected your country?
Yes (Y) or No (N) _____

Part 10. Risk reduction in new and existing educational facilities

The purpose of this section is to describe the capacity of government agencies at any level of government to implement risk reduction in new and existing educational facilities.

43. Have schools in your country been assessed for vulnerability to **earthquake shaking or ground failure, or the potential exposure to inundation by tsunami or dam failure or volcanic debris flows?**
Yes (Y) or No (N) _____

44. Have school buildings been assessed for danger to students and teachers from falling contents (book shelves, laboratory equipment, storage cabinets)?
Yes (Y) or No (N) _____

45. ***If Yes to either of the two questions above***, how were/are assessments conducted (how often, by whom, how), and what proportion of schools is considered in each risk category?

46. Please describe any recent experience with schools and earthquakes, tsunamis or volcanic activity in your country that would shed light on the strengths and weaknesses of your programs or that will help others improve their programs.

47. Is there anything you would like to add that is relevant to describing the policies and practices regarding the safety of children at school during natural hazard events?