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Responding to Global Earthquake Hazards

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PAGER—Rapid Assessment of an Earthquake's Impact

PAGER (**P**rompt **A**ssessment of **G**lobal **E**arthquakes for **R**esponse) is an automated system that produces content concerning the impact of significant earthquakes around the world, informing emergency responders, government and aid agencies, and the media of the scope of the potential disaster. PAGER rapidly assesses earthquake impacts by comparing the population exposed to each level of shaking intensity with models of economic and fatality losses based on past earthquakes in each country or region of the world. Earthquake alerts—which were formerly sent based only on event magnitude and location, or population exposure to shaking—now will also be generated based on the estimated range of fatalities and economic losses.

The U.S. Geological Survey's National Earthquake Information Center (NEIC), in Golden, Colorado, locates over 30,000 earthquakes a year. Tragically, about 25 of these cause significant damage, injuries, or fatalities. In the past, the U.S. Geological Survey (USGS) primarily relied on the experience and intuition of its on-duty seismologists to estimate the impact of an event. To quantify and improve the accuracy of the assessment, the USGS has developed PAGER, an automated system for rapidly estimating the shaking distribution, the number of people and settlements exposed to severe shaking, and the range of possible fatalities and economic losses. The estimated losses trigger the appropriate color-coded alert, which determines suggested levels of response: no response needed (green), local/regional (yellow), national (orange), or international (red).

In addition to direct alert notifications, PAGER provides important supplementary information, including comments describing the dominant types of vulnerable buildings in the region, exposure and any fatality reports from previous nearby earthquakes, and a summary of regionally specific information concerning the potential for secondary hazards, such as earthquake-induced landslides, tsunami, and liquefaction.

PAGER results are generally available within 30 minutes of a significant earthquake, shortly after the determination of its location and magnitude. However, information on the extent of shaking will be uncertain in the minutes and hours following an earthquake and typically improves as additional sensor data and reported intensities are acquired and incorporated into models of the earthquake's source. Users of PAGER need to account for the inherent uncertainty in shaking and loss estimations and always seek the most current PAGER release on the USGS Web site for any earthquake.

The PAGER Process

In general, the shaking-related impact of an earthquake is controlled by the distribution and severity of shaking, the population exposed to each shaking intensity level, and how vulnerable that population is to building damage at each intensity level. Population vulnerability is dominated by the degree of seismic resistance of the local building stock. The PAGER system takes all these factors into account. At the heart of PAGER are the timely and accurate earthquake location and magnitude determinations that the USGS has been producing for decades. PAGER uses these earthquake parameters to calculate estimates of ground shaking by using the methodology and software developed for ShakeMap (http://earthquake.usgs.gov/shakemap/). The number of people exposed to each shaking intensity level is then calculated by combining the maps of estimated ground shaking with a comprehensive worldwide population database (Landscan, from Oak Ridge National Laboratory).

Next, based on the population exposed to each intensity level of shaking, the PAGER system estimates total losses based on country-specific models developed from economic and casualty data collected from past earthquakes. Finally, the alert levels are produced, determined by estimated ranges of fatalities and economic loss, with the higher of the two setting the overall alert level. The alert level determines which users are actively notified, and, at the same time, all PAGER content is automatically distributed to the Web on the USGS Earthquake Hazards Program Web pages, as part of the earthquake summary information, for immediate consumption.

Damage to structures in downtown Concepcion, Chile, due to the February 27, 2010, earthquake. Photograph courtesy of Walter Mooney, USGS.

USGS
science for a changing world

Earthquake Shaking **Red Alert**

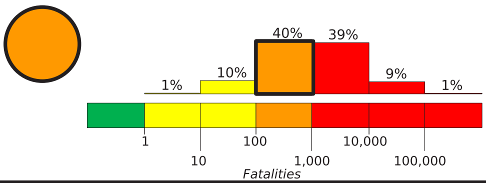
GSN ANSS USAID FROM THE AMERICAN PEOPLE

M 8.8, OFFSHORE MAULE, CHILE

Origin Time: Sat 2010-02-27 06:34:14 UTC (01:34:14 local)
Location: 35.85°S 72.72°W Depth: 35 km
FOR TSUNAMI INFORMATION, SEE: tsunami.noaa.gov

PAGER Version 3
Created: 3 hours, 10 minutes after earthquake

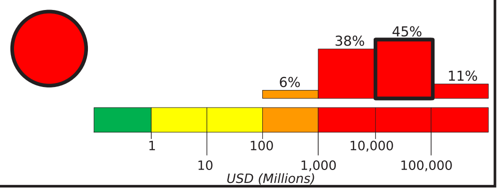
Estimated Fatalities



Red alert level for economic losses. Extensive damage is probable and the disaster is likely widespread. Estimated economic losses are 3-20% 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



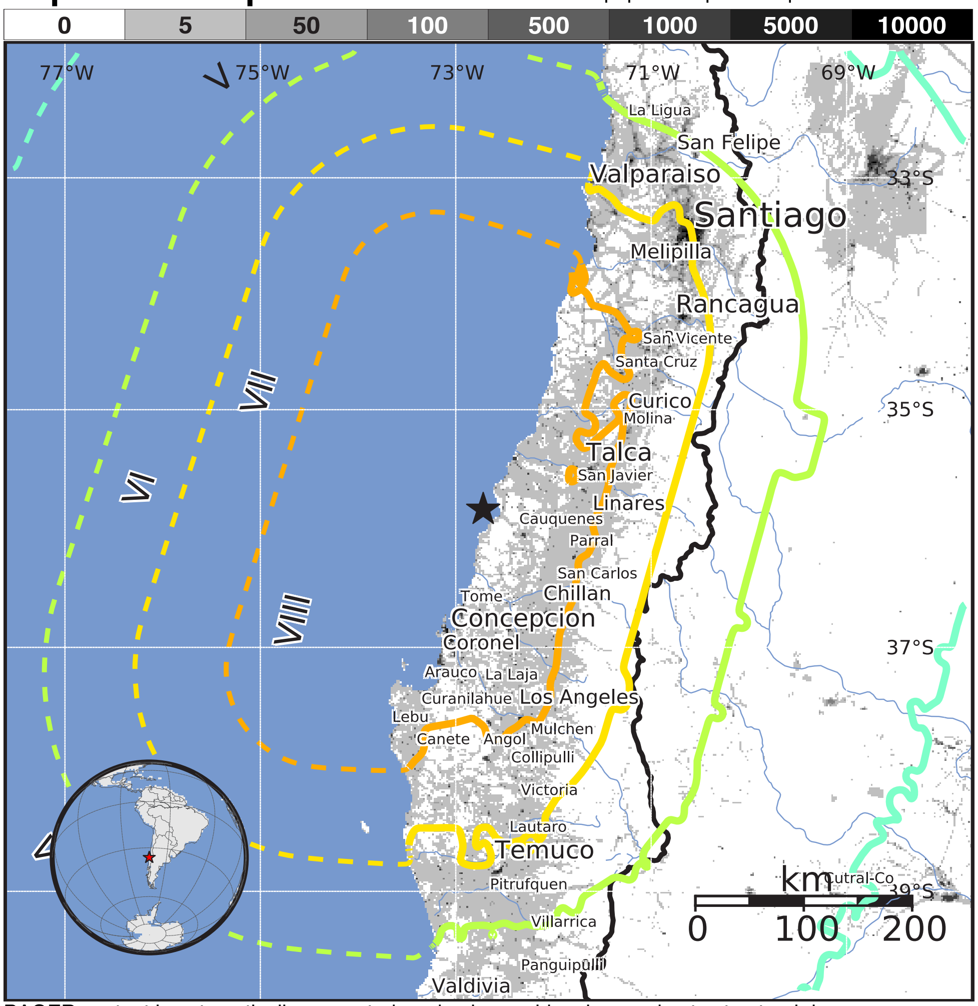
Estimated Population Exposed to Earthquake Shaking

ESTIMATED POPULATION EXPOSURE (k = x1000)		- -*	- -*	488k*	2,150k*	3,654k	6,407k	3,074k	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 partially confined masonry and unreinforced masonry.

Historical Earthquakes (with MMI levels):

Date (UTC)	Dist. (km)	Mag.	Max MMI(#)	Shaking Deaths
1975-05-10	264	7.8	VIII(69k)	0
2004-08-28	229	6.5	IX(346)	0
1985-03-03	313	7.9	VII(7,023k)	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	**Arauco**	**25k**
VIII	Lota	50k
VIII	**Concepcion**	**215k**
VIII	Constitucion	38k
VIII	Bulnes	13k
VIII	Cabrero	18k
VII	**Temuco**	**238k**
VI	**Valparaiso**	**282k**
VI	**Santiago**	**4,837k**
V	Mendoza	877k
IV	Neuquen	242k

bold cities appear on map (k = x1000)

Event ID: us2010tfan

Prompt Assessment of Global Earthquakes for Response

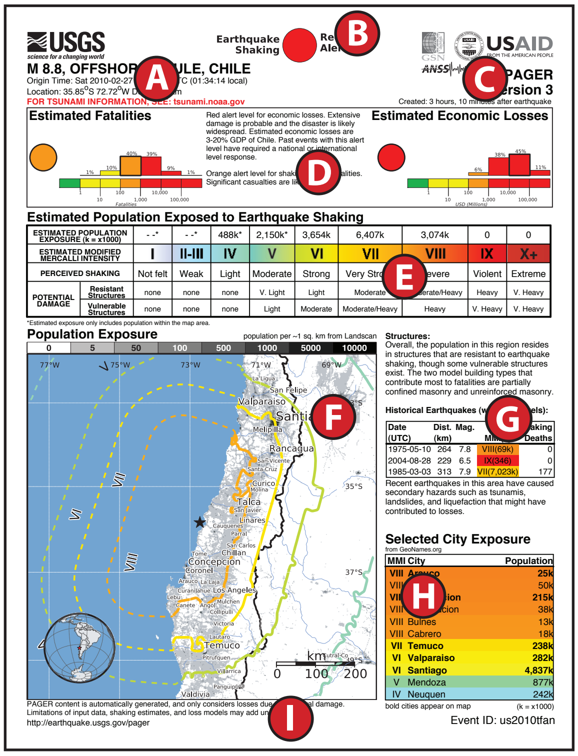
Background

PAGER provides shaking and loss estimates following significant earthquakes anywhere in the world. These estimates are generally available within 30 minutes and are updated as more information becomes available. Rapid estimates include the number of people and names of cities exposed to each shaking intensity level as well as the likely ranges of fatalities and economic losses. PAGER does not consider secondary effects such as landslides, liquefaction, and tsunami in loss estimates at this time. For tsunami warnings see http://tsunami.noaa.gov/.

Information on the extent of shaking will be uncertain in the minutes and hours following an earthquake and typically improves as additional sensor data and reported intensities are acquired and incorporated into models of the earthquake's source. Users of PAGER need to account for uncertainty and always seek the most current PAGER release for any earthquake.

PAGER alerts are available in a one-page summary and Web pages with extended content at http://earthquake.usgs.gov/pager/.

A **Summary of the basic earthquake parameters**, including origin time, local time, magnitude, hypocenter, and the name of the region where the earthquake took place. For events with high likelihood of a tsunami, a link to the NOAA tsunami Web page is provided (bold red text).



B **Earthquake Impact Scale summary alert level**. The higher of the two alert levels (D) is shown as the summary alert at the top-center of the page.

C **The version of the PAGER alert and the time the alert was created**. New versions of the alert are generated when the earthquake information is improved as supplemental ground-shaking constraints become available.

D **Earthquake Impact Scale alert levels** for fatalities (left) and economic losses (right). The alert levels are based on the range of most likely losses due to earthquake shaking; the uncertainty in the alert level can be gauged by the histogram, depicting the percent likelihood that adjacent alert levels (or fatality/loss ranges) occur. Accompanying text clarifies the nature of the alert based on experience from past earthquakes. If the economic alert is yellow or greater, the text will also give a range of economic losses in terms of the country's Gross Domestic Product. The higher level of the two alerts is shown as the summary alert at the top-center of the page (B).

E **Table showing population exposed** to different estimated Modifed Mercalli Intensity (MMI) levels and the possible damage at different intensity levels for resistant and vulnerable structures. MMI describes the severity of an earthquake in terms of its effect on humans and structures and is a rough measure of the amount of shaking at a given location. Unlike earthquake magnitude, intensity varies with distance from the fault. Population outside the map bounds are not included in the totals.

F **Map of MMI contours** plotted over the Landscan (Oak Ridge National Laboratory) population base map. The regions labeled with Roman numeral MMI values are separated by half intensity unit contour lines, e.g., 5.5, 6.5, 7.5. The total population exposure to a given MMI value is obtained by summing the population between the contour lines. This total is shown in the population exposure table (E).

G **Region-specific structure and earthquake commentary**. The Structures comment may contain the most vulnerable building type(s) in the region or a general description of the vulnerability of the buildings in the region. The Historical Earthquakes section includes a table of population exposure and fatalities for three previous nearby earthquakes, and, in some cases, the potential for fires, landslides, liquefaction, or other hazards, based on past earthquakes in the region, will be noted.

H **Table of MMI estimates for selected settlements**. A maximum of 11 settlements that fall within the map boundary are included in the table. The table contains country capitals and the six settlements with the highest estimated intensity. The remaining settlements listed are selected by population. Settlement name, location, and population are obtained from the freely-available GeoNames geographical database (GeoNames.org).

I **Footer**, including a link to the PAGER Web page, the event-identification number, and a disclaimer noting that the content was automatically generated and has additional sources of uncertainty. All possible uncertainties are not considered in the determination of estimated earthquake fatalities and economic losses; the actual impact of the earthquake may differ from PAGER's automatically generated estimate.

The PAGER Earthquake Impact Scale

PAGER uses a new Earthquake Impact Scale (EIS) that is based on two complementary criteria. The first criterion is the estimated cost of damage; this is most suitable for domestic events and those in earthquake-resistant communities. The second criterion, representing estimated ranges of fatalities, is generally more appropriate for global events, particularly in developing countries. Simple thresholds, derived from the systematic analysis of past earthquake impact and associated response levels, turn out to be quite effective in communicating predicted impact and response needed after an event, characterized by alerts of green (little or no impact), yellow (regional impact and response), orange (national-scale impact and response), and red (international response). Corresponding fatality thresholds for yellow, orange, and red alert levels are 1, 100, and 1,000, respectively. For damage impact, yellow, orange, and red thresholds are triggered by estimated losses reaching $1 million, $100 million, and $1 billion, respectively. The rationale for this dual approach to earthquake alerting stems from the recognition that relatively high fatalities, injuries, and homelessness dominate in countries where local building practices typically lend themselves to high collapse and casualty rates, and it is these impacts that drive prioritization for international response. In contrast, it is often financial and overall societal impacts that trigger the level of response in regions or countries where prevalent earthquake-resistant construction practices greatly reduce building collapse and resulting fatalities.

Since PAGER calculations are available well in advance of ground-truth observations or news accounts, PAGER information can be a primary alerting tool for domestic as well as international earthquake disasters. An example of the PAGER summary product, or onePAGER, is shown on the preceding pages for a recent destructive earthquake in early 2010 near central Chile that killed 547 people. This earthquake reached a red-alert level based on projected economic losses and an orange-alert for estimated fatalities.

Though PAGER uses simple and intuitive color-coded alerting criteria, it preserves the necessary uncertainty measures by which one can gauge the likelihood for the alert to be over- or underestimated. Using the earthquake impact scale, PAGER's rapid loss estimates can be used to adequately recommend alert levels and suggest appropriate response protocols, despite their uncertainties. Demanding or awaiting observations or loss estimates with a high level of accuracy may delay response and increase the losses.

Alert level and color	Estimated fatalities	Estimated losses (U.S. $$)
Red	1,000+	$1 billion+
Orange	100 – 999	$100 million – $1 billion
Yellow	1 – 99	$1 million – $100 million
Green	0	< $1 million

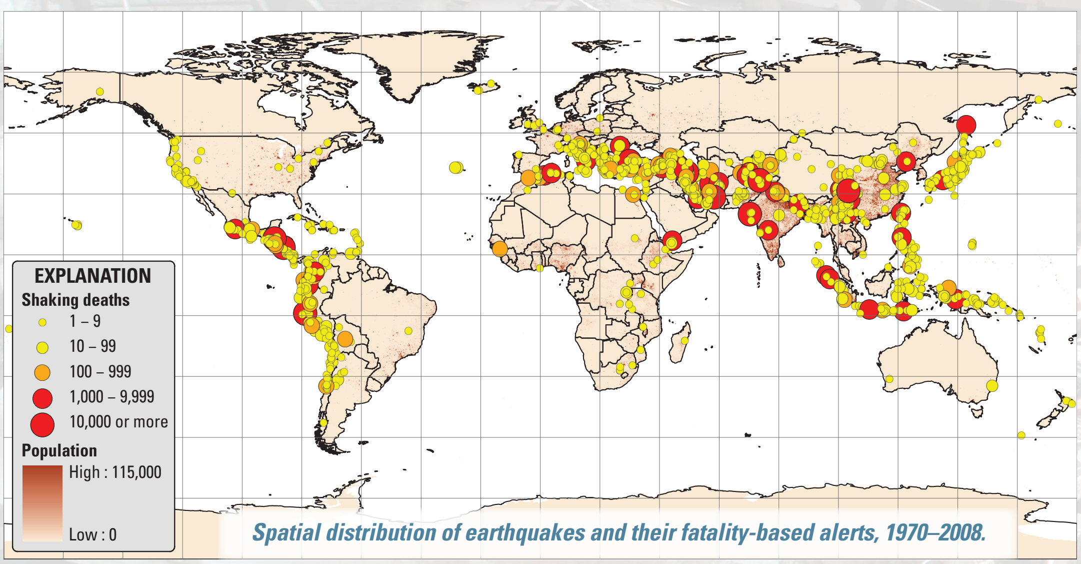
Earthquake Impact Scale with Alert Level thresholds.

Frequency of PAGER Alerts

Over the past 38 years there would have been approximately 17,792 green, 568 yellow, 52 orange, and 49 red alerts. This frequency equates to approximately 15 yellow, 1–2 orange, and 1–2 red alerts per year. The map below shows the spatial distribution of earthquakes and the fatality-based alerts that would have been produced over the past 38 years (1970 through mid-2008). The spatial distribution reflects relative hazard, population exposure, and building vulnerability. In the United States, high-fatality alert levels are, as expected, much less frequent due to improved building codes and practices in areas of high seismicity.

Ongoing PAGER Developments

The USGS is improving the PAGER system to include more comprehensive loss-estimate methodologies that take into account more detailed building inventories representing sub-country-level regional variations, more complete population demographics (including time of day population shifts), and better tools to compute building damage. Such datasets are very difficult and time consuming to acquire and are not available for many areas of the globe. In particular, more detailed country-level building inventories are key for describing the dominant vulnerable structures that contribute to casualties in the region. Knowledge of the main collapse "culprits" is vital for response, public safety, recovery, and long-term mitigation. Related USGS developments under the auspices of the PAGER Project include rapid determination of fault geometry, size, and rupture characteristics; refined global estimates of seismic soil-amplification patterns; ShakeMap enhancements; ground-motion and loss-uncertainty analyses; and earthquake-induced landslide and liquefaction probability mapping.



Spatial distribution of earthquakes and their fatality-based alerts, 1970–2008.

Acknowledgments

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