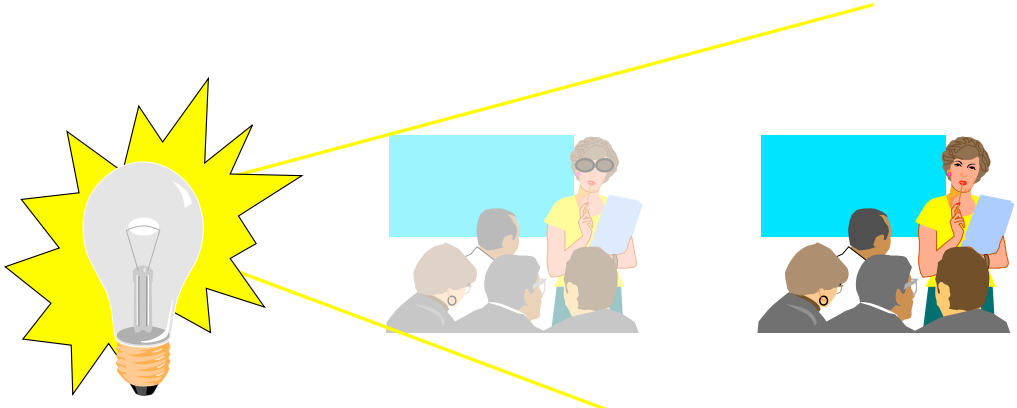
What does an earthquake of a given size feel like, and how much damage does it cause?

How do we express the size of an earthquake? (Two ways)

- We must distinguish between *magnitude* and *intensity*
  - magnitude indicates how much energy was released.
  - intensity is how strong the ground motion is at the felt location.
- Consider a light bulb …



Fixed *magnitude* **Local *intensity*** **Local *intensity***

Earthquake Intensity: factors that contribute

1. Earthquake magnitude
2. Distance from epicentre
3. Ground type
4. Duration

Subjective description of violence and duration of shaking, and damage. Not based on quantitative measures of ground displacement, velocity or acceleration.

The Mercalli Intensity Scale was devised before accurate seismometers were widespread!

Modified Mercalli Intensity Scale: I to XII

Example: VII "Strong"

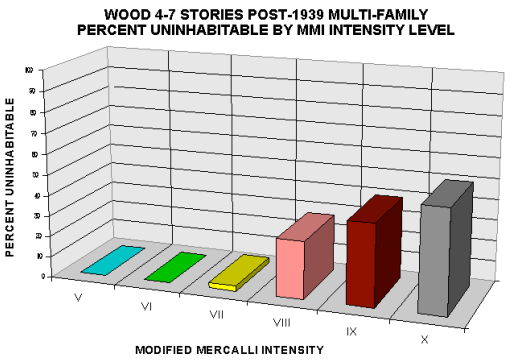
Difficult to stand. Noticed by drivers of motor cars. Hanging objects quiver. Furniture broken. Damage to masonry D, including cracks. Weak chimneys broken at roof line. Fall of plaster, loose bricks, stones, tiles, cornices (also unbraced parapets and architectural ornaments). Some cracks in masonry C. Waves on ponds; water turbid with mud. Small slides and caving in along sand or gravel banks. Large bells ring. Concrete irrigation ditches damaged.

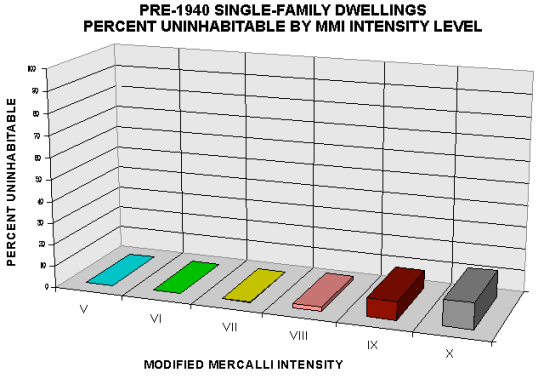
Masonry A: Good workmanship, mortar, and design; reinforced, especially laterally, and bound together by using steel, concrete, etc.; designed to resist lateral forces.
Masonry B: Good workmanship and mortar; reinforced, but not designed in detail to resist lateral forces.
Masonry C: Ordinary workmanship and mortar; no extreme weaknesses like failing to tie in at corners, but neither reinforced nor designed against horizontal forces.
Masonry D: Weak materials, such as adobe; poor mortar; low standards of workmanship; weak horizontally.

Mercalli scale was originally devised (and refined) 1883-1902, modified 1931 and 1958

Full descriptions is from: Richter, C.F., 1958. ***Elementary Seismology.*** W.H. Freeman and Company, San Francisco, pp. 135-149; 650-653.

Why bother with intensity?





- emergency response planning, insurance, loss estimating
- inferring magnitude from subjective historical accounts (such as the Lawson Report on the 1906 SF earthquake)

Generally, maximum intensity correlates with magnitude

Magnitude / Intensity Comparison

Magnitude	Typical Maximum Modified Mercalli Intensity
1.0 - 3.0	I
3.0 - 3.9	II - III
4.0 - 4.9	IV - V
5.0 - 5.9	VI - VII
6.0 - 6.9	VII - IX
7.0 and higher	VIII or higher

Table 3.6 Magnitude versus Length of Shaking

Magnitude	Duration of Strong Ground Shaking in Seconds
8–8.9	30 to 90
7–7.9	20 to 50
6–6.9	10 to 30
5–5.9	2 to 15
4–4.9	0 to 5

But proximity to the *epicenter*, local amplification of shaking, and other effects can make violence and duration of shaking worse than expected

Earthquakes can be unusually devastating due to either
(1) high intensities in areas with high populations (PAGER)
or
(2) other events caused by the earthquake (landslides, fires, tsunamis, etc.)

Bam, IRAN 2003

Kobe Japan, 1995

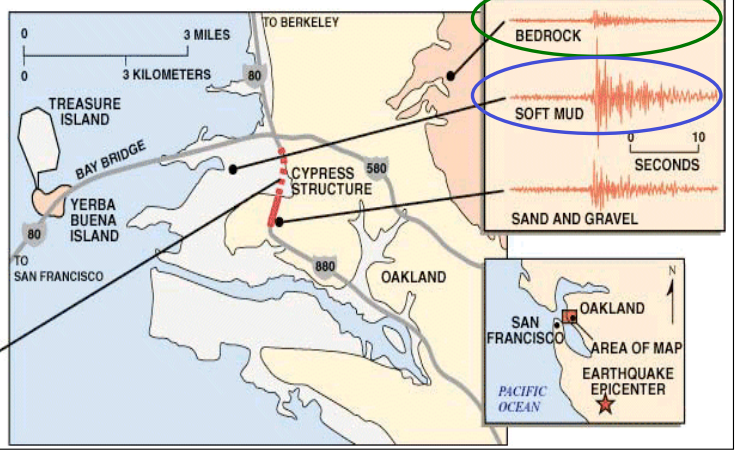
1995 Kobe earthquake

Both:
Magnitude only 6.7 to 6.9 but *intensity of 9 or more in* very populous areas
extreme damage and thousands of deaths

Earthquake Intensity: Effect of ground type

- Harder rocks
  - no amplification
  - a mixture of frequencies
- Softer rocks
  - shaking is **amplified**
  - low-frequencies may reverberate in basins, plus soft rocks absorb high frequencies

http://wrgis.wr.usgs.gov/fact-sheet/fs151-99/



Ground type in Vancouver

- Harder rocks (bedrock - North Vancouver)
  - no amplification
  - all (high and low) frequencies present
- Softer rocks (sediments - Richmond)
  - much amplification
  - loss of high frequency wave energy
  - reverberating low frequency waves

Which area might shake more in an earthquake?


Tidal mud, Richmond


Queen Elizabeth Park (basalt quarry)

Photos by J. Clague

Intensity estimates come from

- felt reports from people (e.g., USGS "Did You Feel It" online questionnaires, generates "community internet intensity map")

- felt reports from seismometers (e.g., USGS ShakeMap, generates "rapid instrumental intensity map" from seismograms)

PAGER: population exposure to various intensities

Part of the USGS "Did You Feel It" questionnaire

While answering all these questions is optional, we encourage you to fill out as many as possible so we can provide a more accurate intensity estimate.

What was your situation during the earthquake? No answer

If you were inside please select the type of building or structure:

No building

If other, please describe:

Were you asleep during the earthquake?

No

Did you feel the earthquake? (If you were asleep, did the earthquake wake you up?)

☐ No ☐ Yes

Did others nearby feel the earthquake?

No answer/Don't know/Nobody else nearby

Your experience of the earthquake:

How would you best describe the ground shaking? No description

About how many seconds did the shaking last?

How would you best describe your reaction? No answer/Don't remember

How did you respond? (Select one.) No answer/Don't remember

If other, please describe:

Was it difficult to stand or walk? No answer/Did not try

Earthquake effects:

Did you notice the swinging/swaying of doors or hanging objects? No answer/Did not look

Did you notice creaking or other noises? No answer/Did not pay attention

Did objects rattle, topple over, or fall off shelves? No answer/No shelves

Did pictures on walls move or get knocked askew? No answer/No pictures

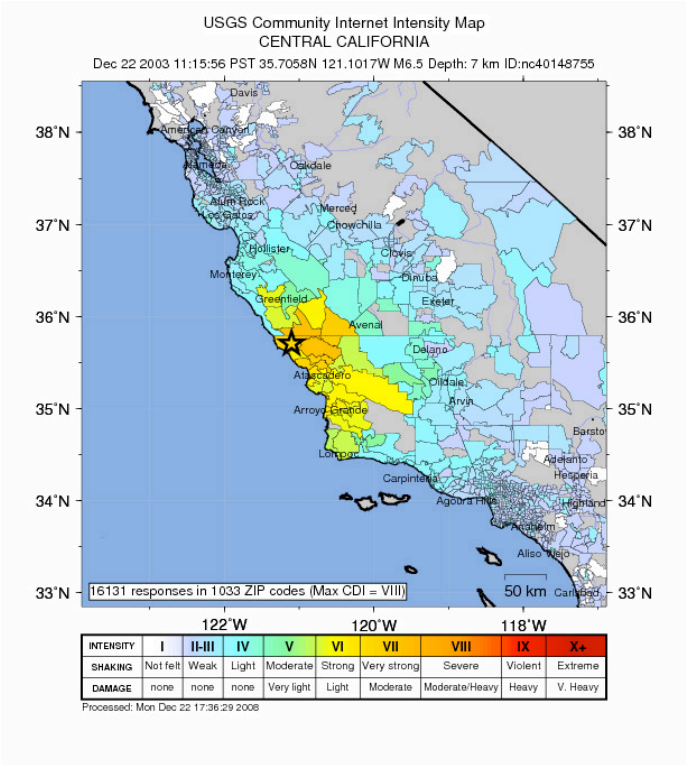
Did any furniture or appliances slide, tip over, or become displaced? No answer/No furniture

Was a heavy appliance (refrigerator or range) affected? No answer/No heavy appliance

Were free-standing walls or fences damaged? No answer/No walls

If you were inside, was there any damage to the building? Check all that apply.

- ☐ No damage
- ☐ Hairline cracks in walls
- ☐ A few large cracks in walls
- ☐ Many large cracks in walls
- ☐ Ceiling tiles or lighting fixtures fell
- ☐ Cracks in chimney
- ☐ One or several cracked windows
- ☐ Many windows cracked or some broken out
- ☐ Masonry fell from block or brick wall(s)
- ☐ Old chimney, major damage or fell down
- ☐ Modern chimney, major damage or fell down
- ☐ Outside wall(s) tilted over or collapsed completely

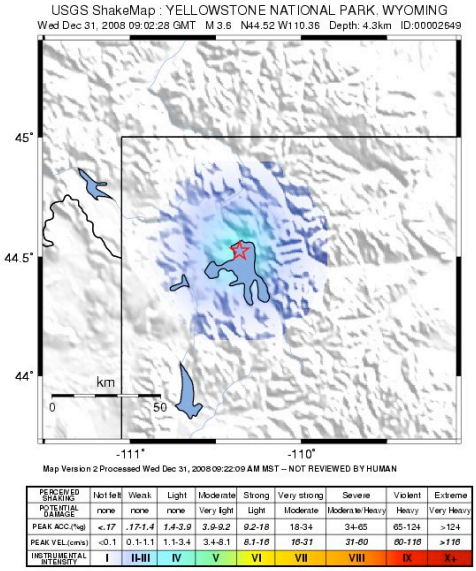


USGS ShakeMap

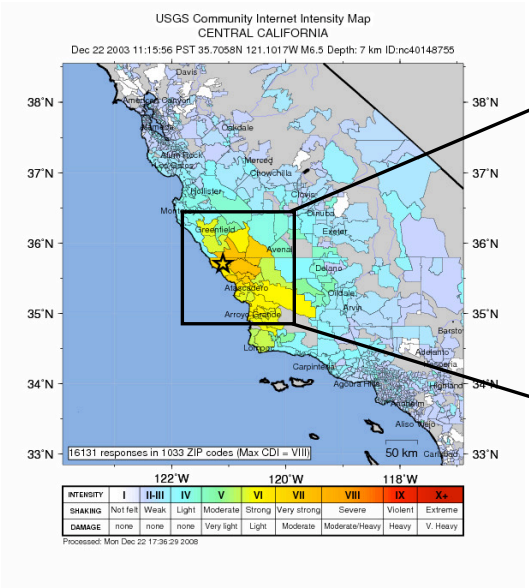
uses records from seismographs

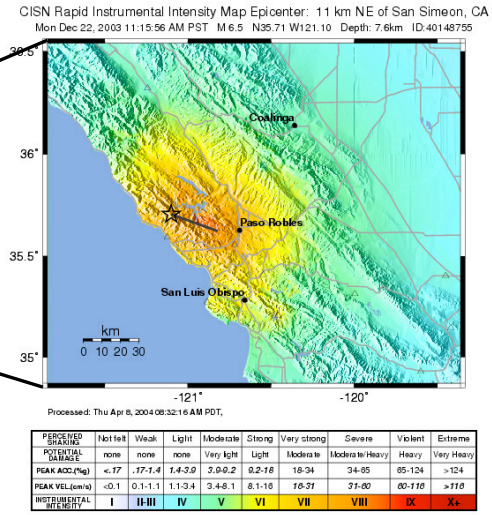
computer automatically generates a map of inferred intensity within minutes

used for emergency response (PAGER map)

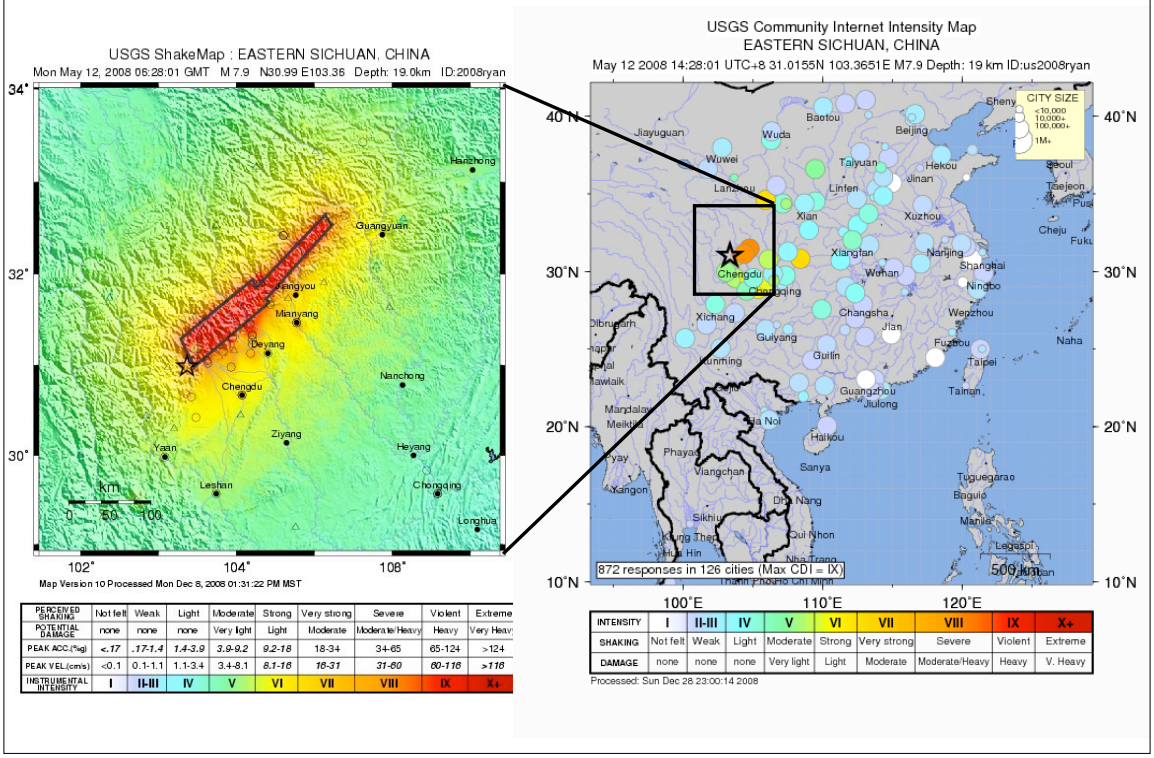


Community intensity map agrees well with instrumental intensity map





Sichuan, China Earthquake Intensity



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+

INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+
SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy

PAGER map for the Sichuan Earthquake

M 7.9 - EASTERN SICHUAN, CHINA

Monday, May 12, 2008 at 06:28:01 UTC

Location: 31.0°N 103.4°E Depth: 19km

Alert version 12

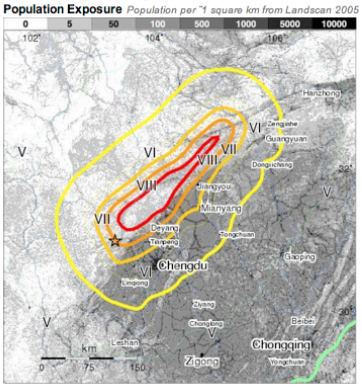
Summary | Maps | Exposure | Cities | Downloads | Details

Estimated Population Exposed to Earthquake Shaking

Est. Modified Mercalli Intensity	Est. Population Exposure (k = x1000)	Perceived Shaking	Potential Structure Damage	
			Resistant	Vulnerable
X	2k	Extreme	V. Heavy	V. Heavy
IX	530k	Violent	Heavy	V. Heavy
VIII	1,124k	Severe	Moderate/Heavy	Heavy
VII	3,815k	Very Strong	Moderate	Moderate/Heavy
VI	18,662k	Strong	Light	Moderate
V	63,137k*	Moderate	V. Light	Light
IV	1,563k*	Light	None	None
II-III	--*	Weak	None	None
I	--*	Not Felt	None	None

*Estimated exposure only includes population within the map area.

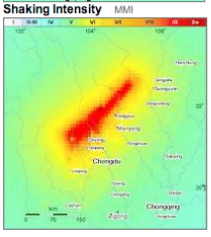
Population Exposure *Population per ~1 square km from Landscan 2005*



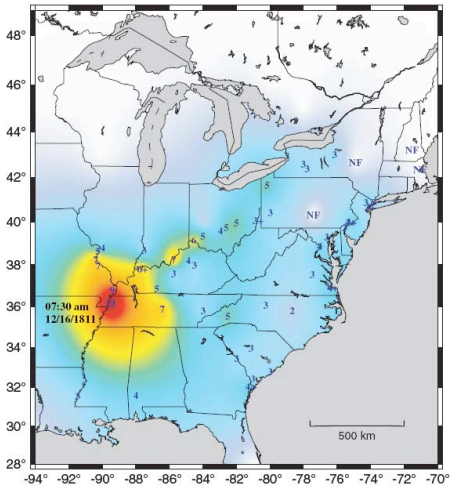
Selected City Exposure

MMI	City	Population
VII	Tianpeng	60k
VII	Jiangyou	127k
VII	Mianyang	264k
VI	Chengdu	3950k
VI	Guangyuan	213k
VI	Linqiong	55k
VI	Deyang	152k
V	Nanchong	7150k
V	Zigong	689k
V	Neijiang	546k
V	Chongqing	3967k

Shaking Intensity MMI

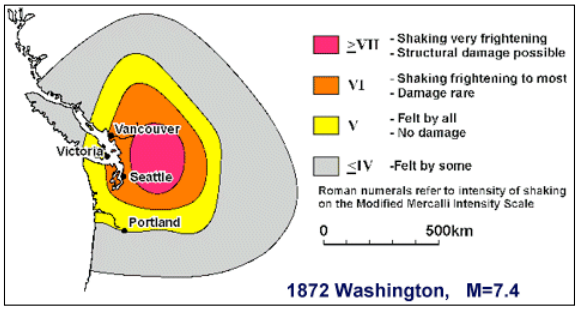


Earthquake intensity for 1811-1812 New Madrid earthquakes, based on historical accounts



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 3. Shaking intensity map for event NM1-A.



Probability of shaking at different Mercalli intensities, in the next 100 years

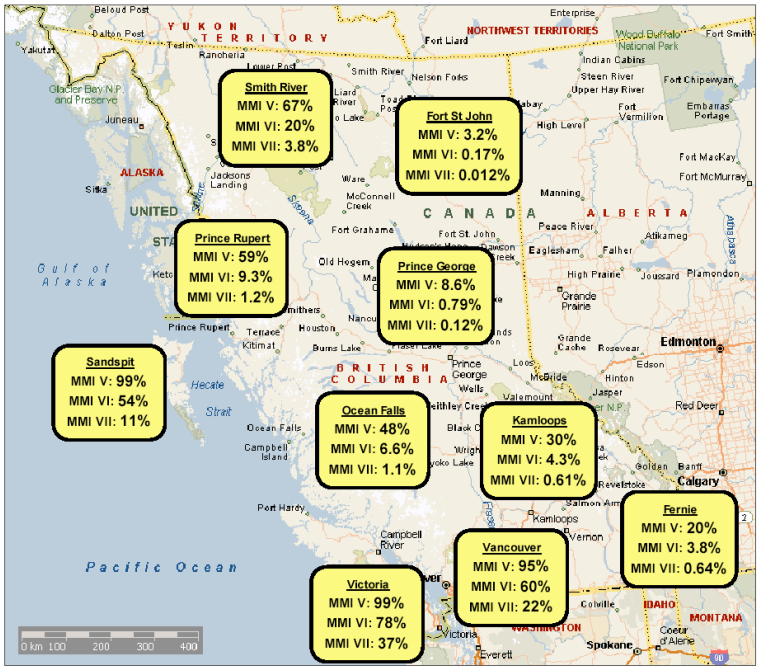


Figure 5. Distribution of earthquake shaking probabilities in BC within a 100-year period (for firm ground)

Onur and Seeman, 2004

http://www.pgc.nrcan.gc.ca/seismo/person/people/pubs/13WCEE1065.pdf

These are minimum values: numbers will be higher on softer ground