Earthquake damage
Two main points
• What are the ways that faulting causes damage?
• Why is there so much variability even between nearby areas in the degree of damage that occurs?

Hazards of faulting
• Generally, quake hazard is from ground shaking
  – But fault trace ground shift can be devastating right on fault trace
• Both greater ground shift and ground shaking in fault zone
• Few structures can withstand ground rupture

Fault zone width
• Legal definition for Special Studies Zone
  – 220 m on either side of mapped fault trace
  – “… zone shall ordinarily be one-quarter mile or less in width, except in circumstances which may require the State Geologist to designate a wider zone.”
• Physical definition depends on how active and well-developed the fault is
  – Width of San Andreas fault zone
    • 1-2 km
    • Weakest in the middle
    • 100-300 m
Example from Nicaragua

- 4-story building on the fault
  - Reinforced concrete structure
- Just 20 cm of fault offset
- Building pancaked

Building straddling fault in Nicaragua. 20 cm of slip in 1972 earthquake caused collapse.

Yanev, p. 29

Ominous furrows after 1971 San Fernando quake

Avoid living in the fault zone

- Could be zoned for parks
- Or, at a minimum, streets
- It's best to live 5 miles or more away from faults
  - Often unrealistic
- Even “creeping” faults are bad news

Living on the scarp

Hayward fault runs thru Berkeley stadium

Creeps some:
- Has moved 5 inches since 1930’s

Yanev, p. 30

Jacopi, 43
UC Berkeley Campus

Hayward fault and stadium

(Won’t hold back the fault)

(SF water supply in 1906

Denali 2002 earthquake in Alaska

The pipeline withstood the powerful quake just as designed, damaged but not ruptured, and not spilling oil.

Examples of problems

• Zoning
  – Daly City
    • Old laws not very good
  – Hayward fault
    • Old laws not very good
  – Salt Lake City
    • No laws
  – San Fernando
    • What were they thinking?
Daly city

- The San Andreas Fault runs through Daly City
- Zoning ignored the presence of the fault
- Now poster city for bad planning

Daly City 1956

- Undeveloped

Daly City in 1966

- Development ignores presence of San Andreas Fault

Hayward Fault zoning prior to legislation in 1972

Good neighborhood plan

- Road, park on fault
- Structures set back from fault traces

Bad building site? Yes

San Fernando, 1971
Relation of danger to faults

- Worst danger near faults
- Most damage within 50 km
- Occasional pockets of damage out to 100-200 km from rupture
  - Usually due to very soft soil
- Shape of isoseismals
  - $M < 6.5$ form circular isoseismals
  - Long rupture: elongated isoseismals

1906 SF quake

- Elongated isoseismal pattern

Soft Sites

- Stronger shaking on
  - Soft soil, Landfill
  - Waterside sites
- Seismic waves grow in amplitude when they pass from rock into less rigid material such as soil
  - Soils behave like jelly in a bowl, which shakes much more than the plate

Soft Soil Mechanics

- Energy is conserved
- Energy in a wave is
  \[ \text{Wave velocity} \times \text{density} \times \text{Amplitude}^2 \]
- Therefore, in softer, lower velocity soils,
  \[ \text{Wave velocity} \times \text{density} \times \text{Amplitude}^2 \]
Soft ground

Pavement
Over dirt

Influence of soft ground

- Dangerous geology
  - Old filled stream beds
  - Sand dunes
  - Water-saturated muds

Softness can vary on a fine scale
- Motion can vary by factor of 4 in 100 m

- 1906, near-surface geology mattered
  - Santa Rosa and San Jose as hard hit as SF due to soft ground downtown

1906 SF settling

1906 damage in Santa Rosa

Bay Area soil conditions

- Correlates with damage pattern
- Strongest damage is were water-deposited sediments are

Keller, 4-14

Liquifaction danger

This map is intended for planning use only. It is based on work by Wm. Letts & Assoc. and USGS. More detailed maps are needed for site development decisions. Hazard maps derived from this map are also available. A more detailed version of this map is available at http://quake.ubc.ca.gov. Source: Kudsen & others, 2000.
More on soft ground

• Mexico City badly damaged in 1985
  – Quake more than 200 miles away
  – Extremely soft soil downtown
  – 10,000 deaths

• Soft sites common
  – LA, Bay Area, Seattle, Salt Lake City, Anchorage, Boston, New Orleans ...

Destruction of subway in Kobe, Japan

Extreme case: Soil Liquefaction

• **Liquefaction**: compaction of water-saturated soil during intense shaking allows water to flow upward and the soil loses its shear strength and flows, becoming liquefied into a kind of quicksand
  – Liquefaction strikes soft, sandy water-saturated soils
    • Usually low-lying and flat
  – Buildings may tilt or sink into liquefied sediments; tanks may float

General liquifaction criteria

• Historical criteria
  – What liquefied last time?

• Geological criteria
  – What soil is similar to soils that liquefied last time

• Compositional criteria
  – See next slide

• State criteria
  – Relative density, pre-stress
Liquifaction criteria

- Fraction finer than 0.005 mm <15%
- Liquid Limit, LL <35%
  - “Liquid limit” - water content above which material acts as a liquid
- Natural water content > 90%
- LL Liquidity Index <0.75

Liquefaction during 1995 earthquake Kobe, Japan

Sinking in quick sand in Niigata 1964

Rising sewage tank in Niigata 1964

Poorly connected bridges

Buildings tilted in liquefied sand due to 1964 Niigata, Japan quake
Landfills
- Often poorly compacted material
- Organic material decays, producing voids and weak spots that can settle
- Therefore, expect
  - Strong shaking in earthquake
  - Ground can settle substantially
- Newer landfill better compacted, may still have problems in large quake

More about landfills
- Often impossible to detect
  - Pre-WWII methods often leave voids
- Clues
  - Sidewalk cracks, misalignment of adjacent buildings, doors, or windows can be clues

Clues to settlement:
- Tilting buildings
- Differential settlement

Riverbanks, lakesides
- Riverbanks are often thick layers of soft, silty clay with a lot of water
- Same problems for edges of bays and soil under levees
- Many downtowns are on riverbanks
- Riverbank towns often have old buildings
- Many roadways, railways, pipelines along the water

Riverbank collapse

Lake Merced - 1957 Daly City EQ

Salinas River in 1906
1959 Hebgen Lake

Liquefaction damage at Hyogo Port, Kobe, Japan

Liquefaction damage on landfill at Port Island, Kobe, Japan

Avoiding liquifaction

- Don’t build on bad soil
- Build liq.-resistant structures

Improve the soil

- Vibrofloatation
- Dynamic compaction
- Stone columns
- Compaction piles
- Compaction grouting
- Improve drainage

Cliffs and Ridges

- Sometimes experience greater shaking because unsupported by ground and rock on one or both sides
  - Example: Glenridge, Bel Air in LA
- More often, less shaking
  - Harder rock
- Landslide and rockfall potential
- Examples
  - Santa Monica Mts. did OK in Northridge
  - Santa Cruz Mts. had some problems in Loma Prieta
    - But mainly due to bad construction

Summary: Hazards of various geological foundations

- Soft soils - stronger shaking, settlement
- Wet soils - liquefaction potential, landsliding potential
- Cliffs and ridges - stronger shaking, landsliding potential

Landslides

- Landslide: a chunk of ground, usually wet and weak, breaks loose, then slides down hill
- Landslide potential can exist on hillsides and steep slopes
  - From both natural and manmade causes
  - Increased potential when wet
- Earthquakes often trigger landslides

Landslide schematic

Angle of repose: How steep?
Angle of repose: steepest slope at which loose material will lie without cascading down.

Angle of repose increases as size of particles increases.

Angle of repose depends on amount of moisture between particles.

Kinds of slides (mass wasting):
- Landslides
  - Mud slides
  - Debris flows (volcanoes)
  - Rock falls
  - Generic landslides
- Snow and Ice
  - Avalanches
- First, we’ll look at slow slides

Kinds of slides:
- Earthflow
  - Australia, also visible along Hwy 5 (NOAA slides)
- Pacific Palisades slumps (NOAA slides)
- Northridge slide (NOAA slides)

Background:
- Seasonal problem, worst after heavy rains
  - Luckily, Loma Prieta, San Fernando, and Northridge quakes struck in dry weather
- 1971 San Fernando quake
  - Even in dry season, caused 1000+ landslides with 50+ feet of sliding
- 1994 Northridge quake
  - Caused 9000+ slides because energy was directed towards mountains
La Conchita
near Santa Barbara
1995
No one hurt

July 10, 1996
Yosemite slide
70,000 cubic meters of rock
Fell 500 meters
- Registered as M 2 seismic event
Near Glacier Point, above valley
200 ton fall the next day killed one
and injured 14 at Granite Point
- A regular problem at Yosemite

Slide path

Results of rocks and wind

Big slide
1906, Frank, Alberta,
over in 2 minutes,
buried a whole town

Picture from the time

Coal mine in mountain
may have started slide,
about 100 dead.
Landslides are major West Coast problem

- Rapid tectonics
  - Fast-rising mountains
- Ample rain for lubrication
- Coast heavily built-up
- Earthquakes

California troubles in 1997-98

Example: San Mateo County landslides

Nationwide

- Slides problems mainly coincide with mountains
  - Pacific coast
  - Colorado
  - Appalachians
  - New Hampshire
  - Alaska, Hawaii
- North America
  - 50 deaths, $2,000,000,000 per year

San Fernando landslides 1971, in the dry season
Obscure quake risk
- 1994 Northridge quake
  - Lots of dust floated out over LA
  - Valley Fever
    - Fungus spores in near-surface dust
    - Incidence of Valley Fever higher by a factor of ten in 8 weeks after quakes
    - An extra 5-10 deaths
    - Raised death toll from Northridge
    - First self-referenced Google result


15 m high mudflow:
quake in Tadzhikistan, 1989
Slopes weakened by rain

Hebgen Lake 1959 quake
- M 7.5
- Landslides
- Caused seiches (waves in lake)

Landslide as a dam
- 100m high
- 28 buried
- 1959 quake

Photo courtesy of the Deseret News
Better view of slide
Landslide: Peru, 1970
due to quake,
20,000 killed,
16 km slide,
4 km drop,
with glacial ice
Keller, 13-9

Before After

Path of Peru slide

Picture in previous figure

Turnagain Slide, Anchorage
1964 Alaska

• Slide: 3 km wide and 400 m deep
• A second slide dropped the business district 10 feet
• Slide was previously recognized and mapped
• Area that slid has been rebuilt
  – Best views in town

Yanev, 66

Cross-sections of the bluffs at Turnagain Heights before and after 1964 Alaska quake

Note that area had slides before
After Turnagain slide

Colorado

Known as The Battleship, covers HWY 550 over 250 m with 1 m of snow

Avalanches

Battling avalanches

75 mm mountain howitzer

Another gun