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

- San Andreas Fault zone in the Carrizo Plains
- Imagine tearing on fault trace
- And soft ground near fault trace
- How close is dangerous?

Fault zone width

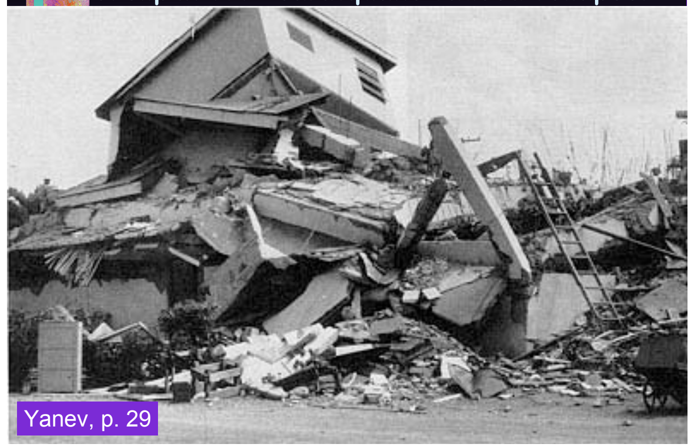
- Legal definition for Special Studies Zone
  - 220 m on either side of mapped fault trace
  - "… zone shall ordinarily be one-quarter mile or less in width, except in circumstances which may require the State Geologist to designate a wider zone."
- Physical definition depends on how active and well-developed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

Fault scarp in Armenia, 1988

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

Yanev, p. 30

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

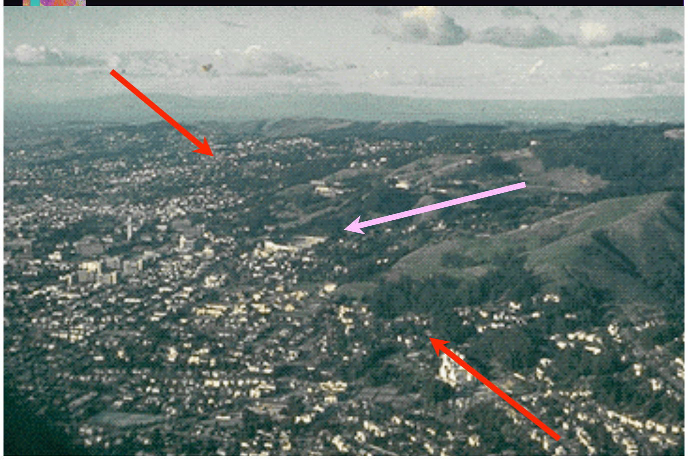
Photo #17 from I.J. Witkind Collection, U.S. Geological Survey
Courtesy of U.S. Geological Survey

Hayward fault runs thru Berkeley stadium

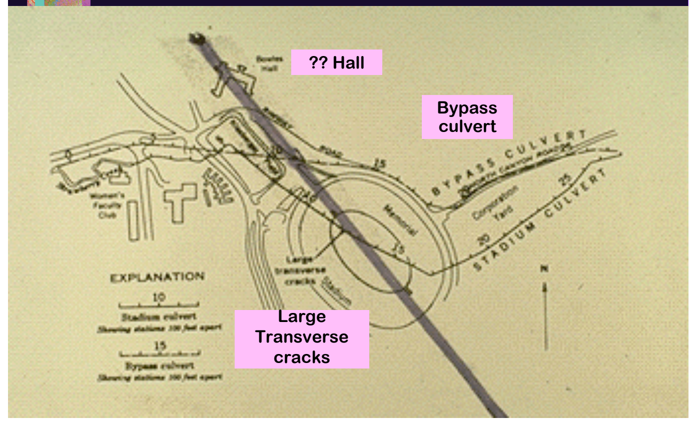
Creeps some:
Has moved
5 inches
since 1930's

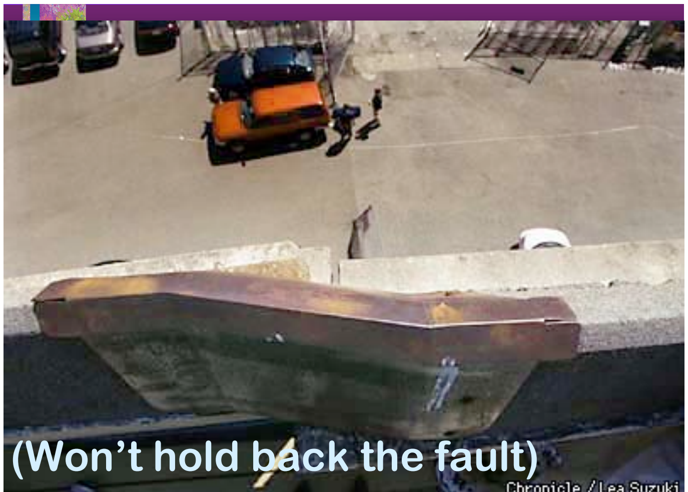
Iacopi, 43

UC Berkeley Campus



Hayward fault and stadium





SF water supply in 1906

30-inch pipe broken at San Andreas Fault

Denali 2002 earthquake in Alaska

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?

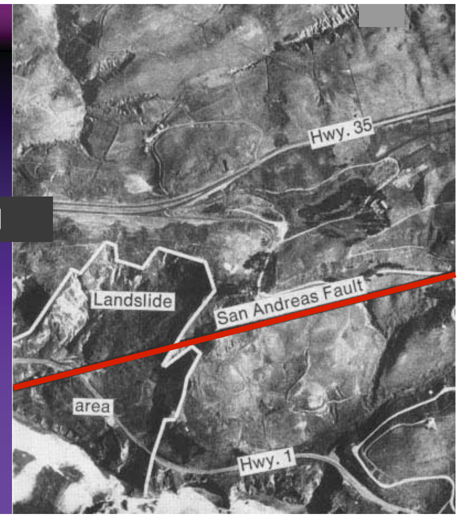
Daly city

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

Yanev, 34

- Undeveloped

Daly City 1956



Daly City in 1966

- Development ignores presence of San Andreas

Yanev, 34

Poor neighborhood zoning prior to legislation in 1972

Hayward Fault
Yanev, 44

Good neighborhood plan

Road, park on fault

- Structures set back from fault traces

Hayward Fault
Yanev, 44

San Fernando, 1971

Bad building site? Yes

Yanev, p. 45

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

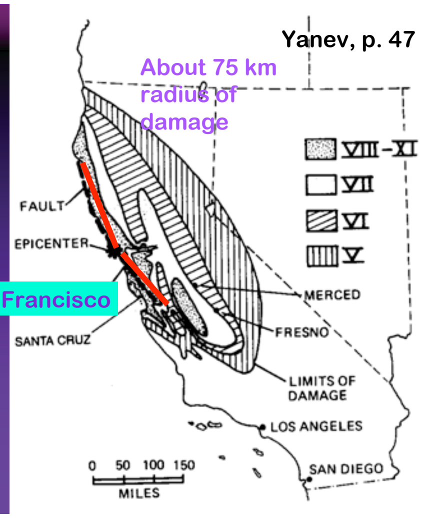
High-rise building

Mexico City, 1985

Keller, 4-13

1906 SF quake

Elongated isoseismal pattern



Next: Soil Effects

- Strength of shaking depends
  - On earthquake size
  - On distance to earthquake (actually to region of large slip)
  - On site
    - nature of the ground just under the structure

Soft Sites

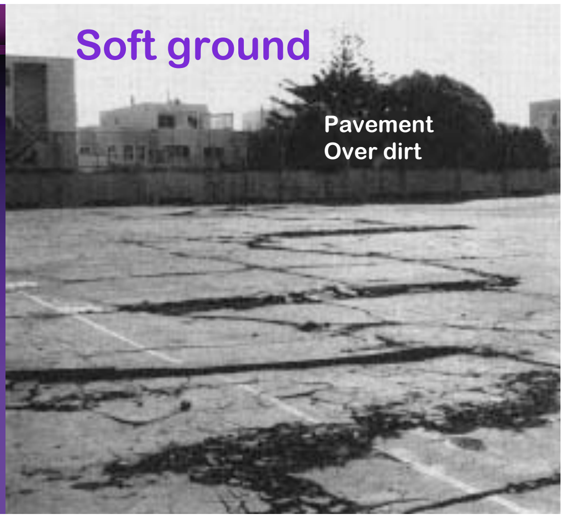
- Stronger shaking on
  - Soft soil, Landfill
  - Waterside sites
- Seismic waves grow in amplitude when they pass from rock into less rigid material such as soil
  - Soils behave like jelly in a bowl, which shakes much more than the plate

Soft Soil Mechanics

- Energy is conserved
- Energy in a wave is
  Wave velocity x density x Amplitude^2
- Therefore, in softer, lower velocity soils,
  Wave velocity x density x Amplitude^2

↓ ↓ ↑

Soft ground



Yanev 49

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

Yanev 53

1906 damage in Santa Rosa

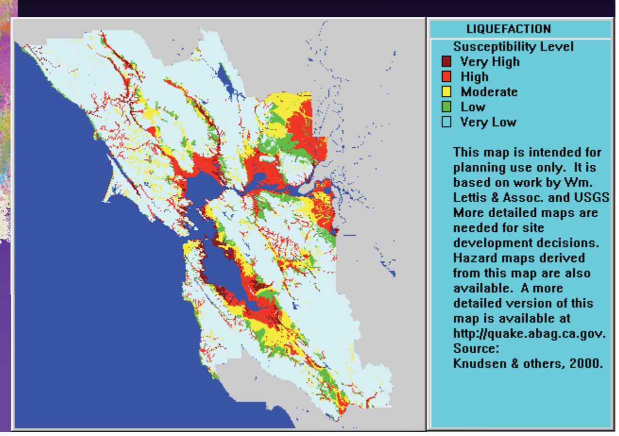
Iacopi 91 City Hall

Bay Area soil conditions

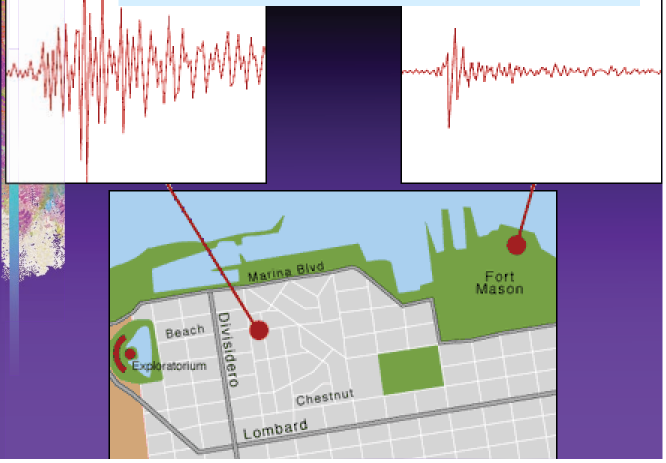
- Correlates with damage pattern
- Strongest damage is were water-deposited sediments are

Keller, 4-14

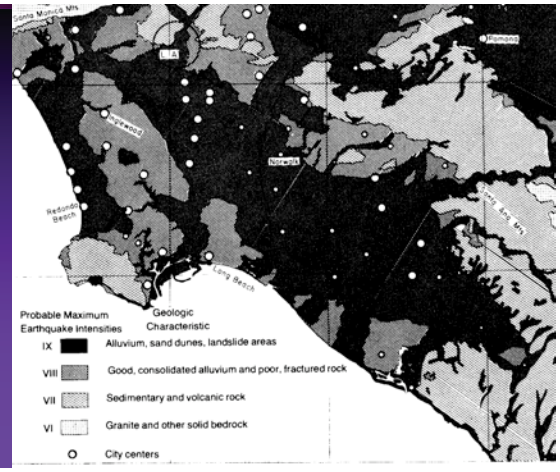
Liquifaction danger



Real case of a site effect



LA shaking pattern predicted from geology

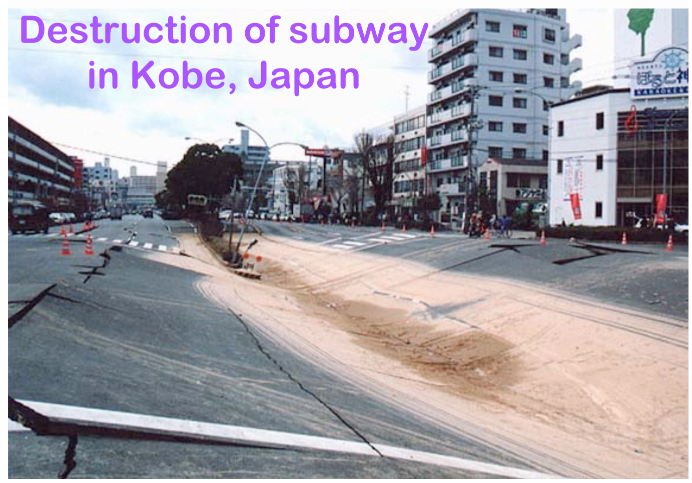


Yanev p. 52

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

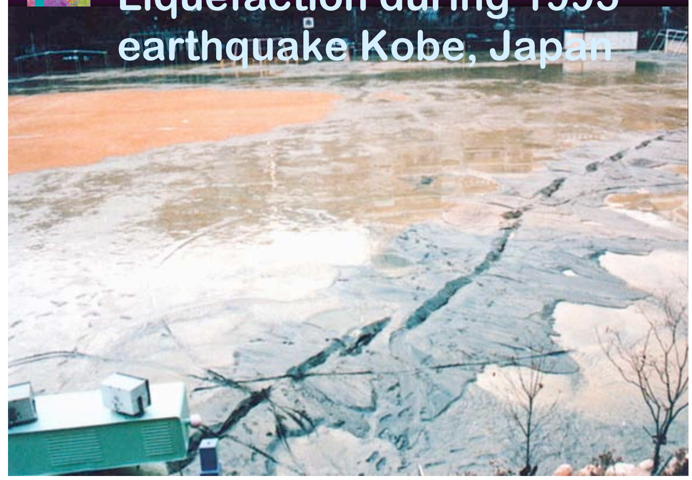
General liquifaction criteria

- Historical criteria
  - What liquified last time?
- Geological criteria
  - What soil is similar to soils that liquified 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

Karl V. Steinbrugge Collection, Earthquake Engineering Research Center, University of California, Berkeley.

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

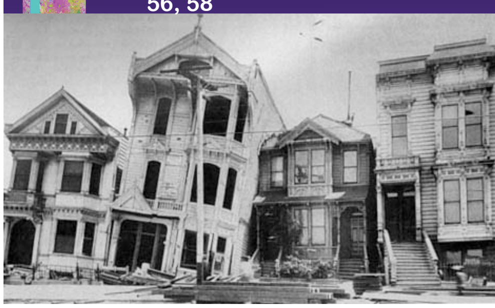
More about landfills

- 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

Yanev 56, 58

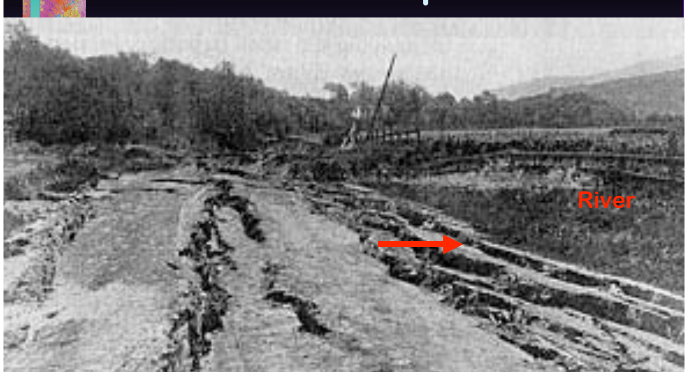
Differential settlement



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

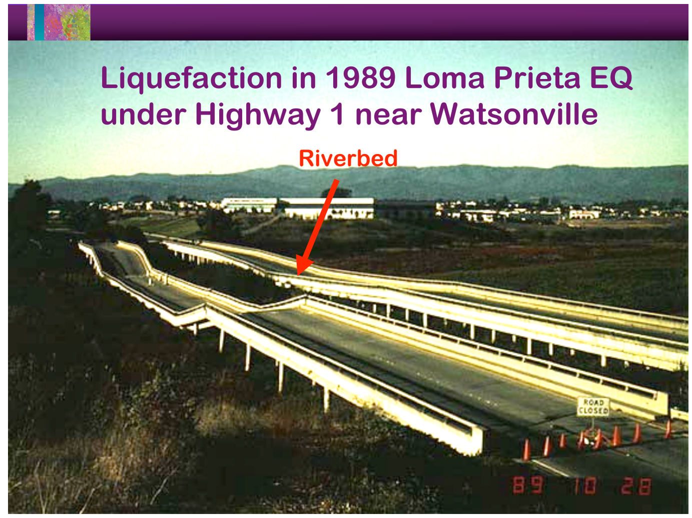


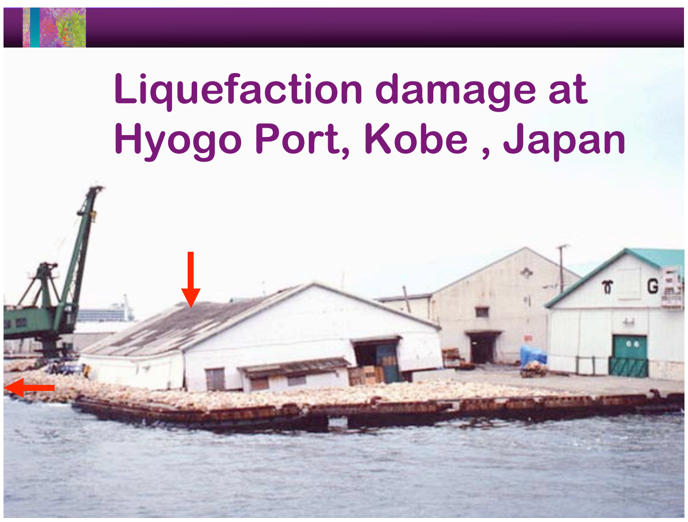
Yanev 59

Salinas River in 1906

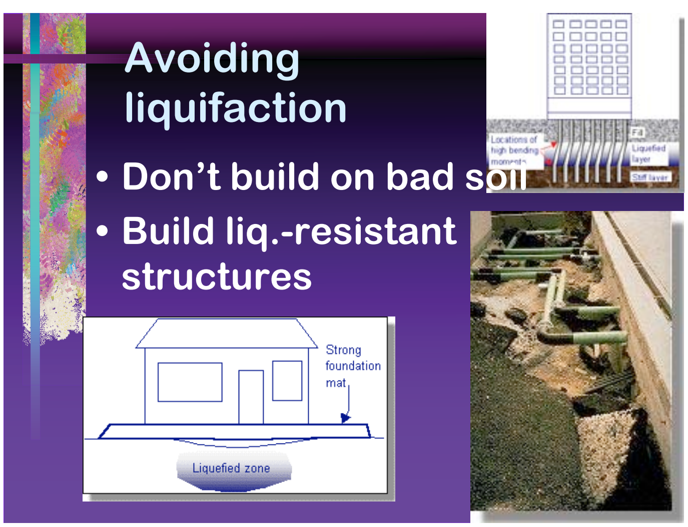
Lake Merced - 1957 Daly City EQ


1959
Hebgen
Lake
Photo by Ray Jones, Deseret News
Courtesy of the Deseret News


Liquefaction in 1989 Loma Prieta EQ under Highway 1 near Watsonville
Riverbed
89 10 28


Liquefaction damage at Hyogo Port, Kobe , Japan


Liquefaction damage on landfill at Port Island, Kobe, Japan
Notice seaward slump

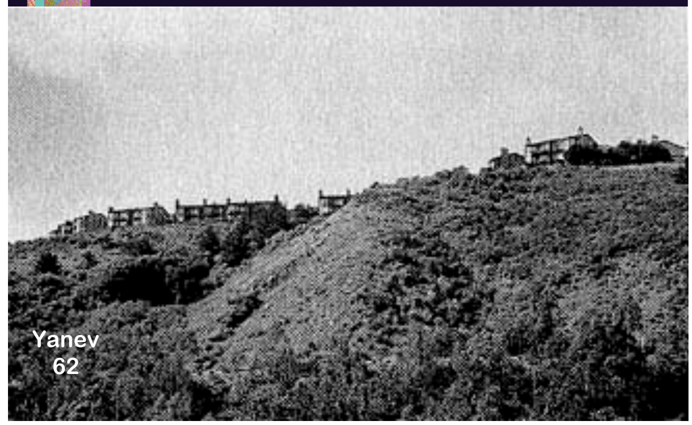

Avoiding liquifaction
• Don't build on bad soil
• Build liq.-resistant structures
Strong foundation mat
Liquefied zone


Improve the soil
• Vibrofloatation
• Dynamic compaction
• Stone columns
• Compaction piles
• Compaction grouting
Improve drainage
http://www.ce.washington.edu/~liquefaction/html/main.html

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

Better or worse?



Yanev 62

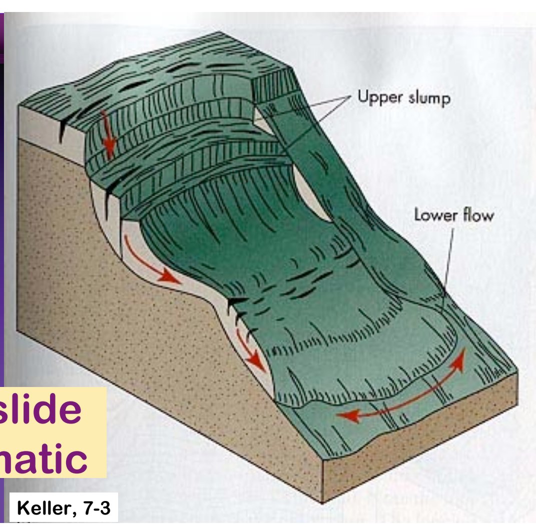
Summary: Hazards of various geological foundations

- 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

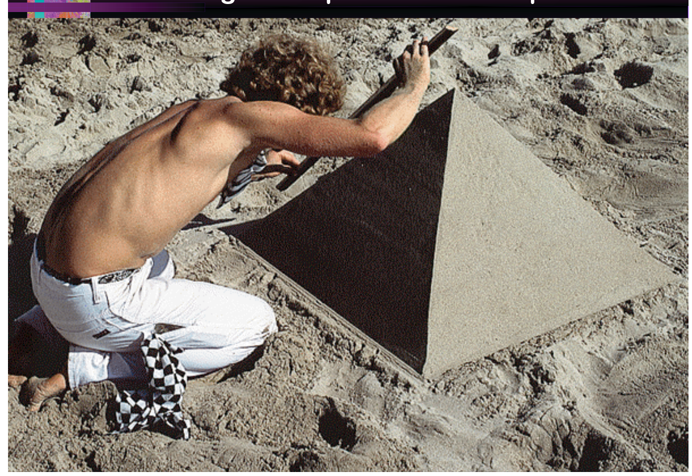
Earthquakes often trigger landslides



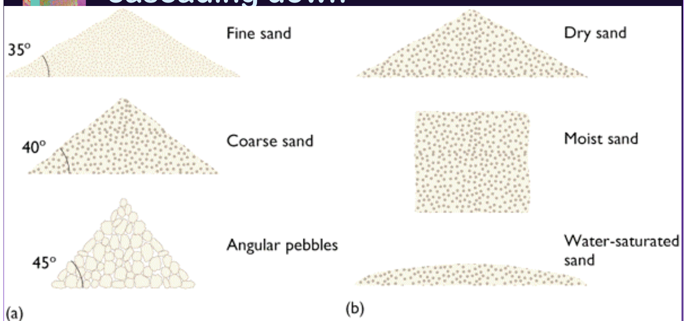
Landslide schematic

Keller, 7-3

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

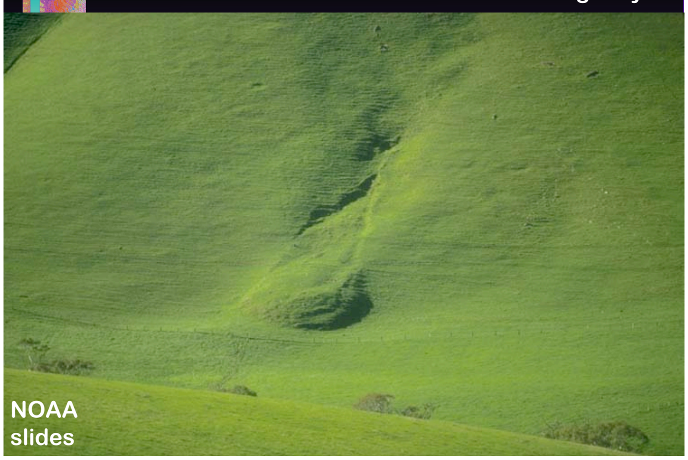
Angle of repose depends on amount of moisture between particles

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

Earthflow

Australia, also visible along Hwy 5

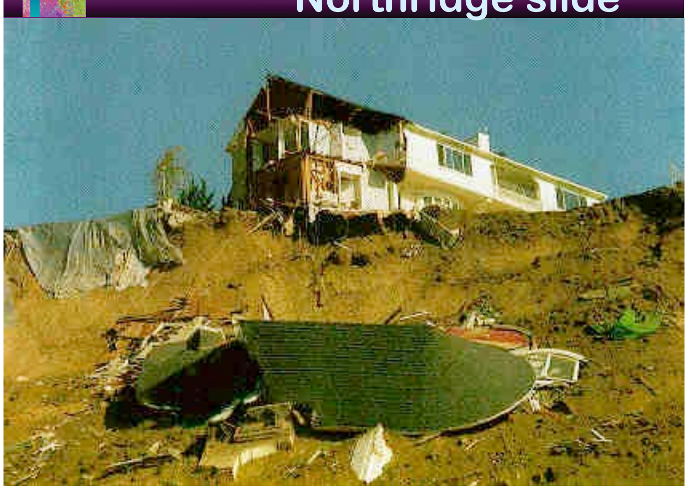


NOAA slides

Pacific Palisades slumps

NOAA slides

Northridge slide



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

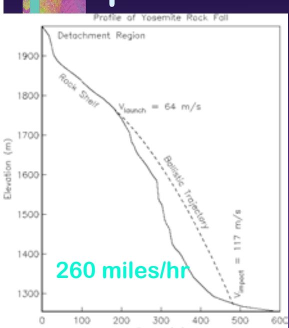
La Conchita

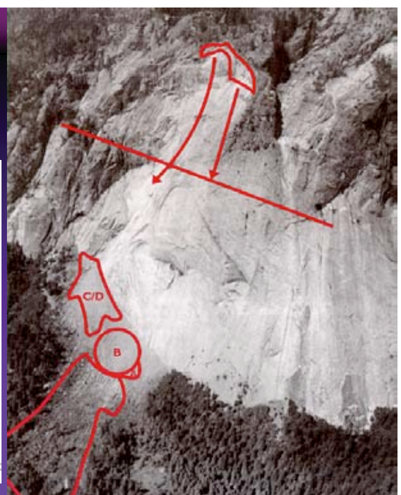
near Santa Barbara
1995
No one hurt

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



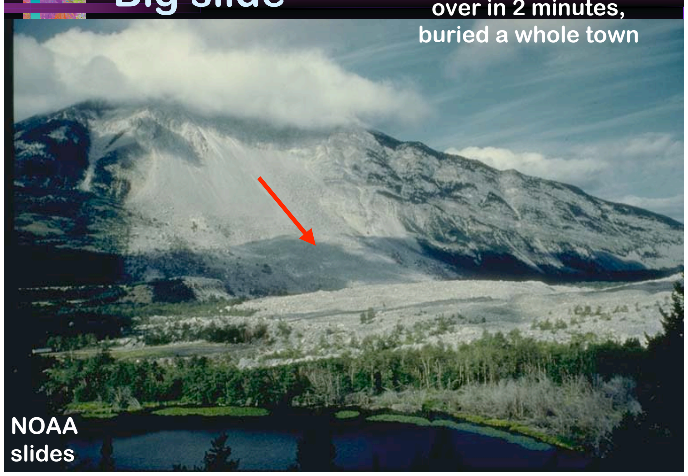


http://www.seismo.berkeley.edu/seismo/events_of_interest/yosemite/eoi_yos.html

Results of rocks and wind

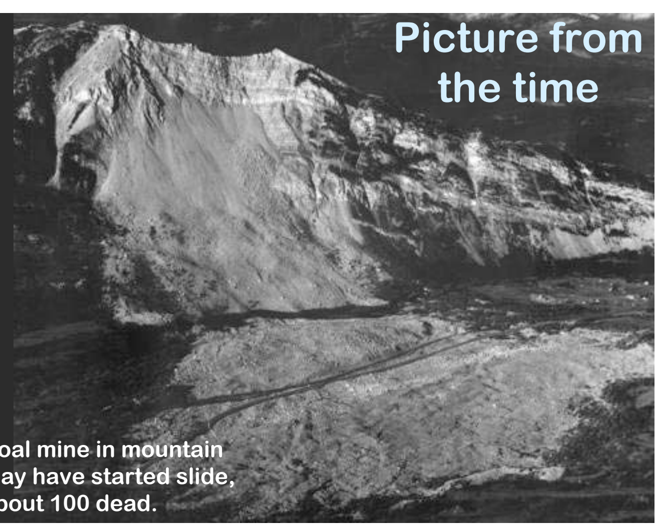
Big slide

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



NOAA slides

Picture from the time



Coal mine in mountain may have started slide, about 100 dead.

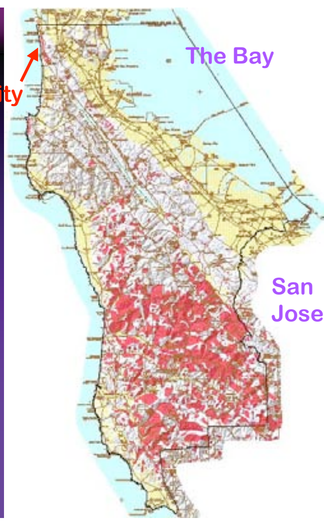
Landslides are major West Coast problem

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

California troubles in 1997-98

Example: San Mateo County landslides

Red areas have slid



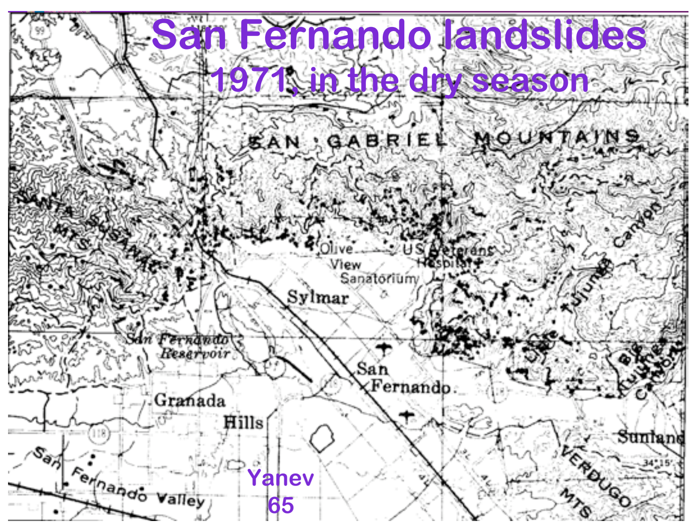
Nationwide

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

National slide hazard

San Fernando landslides

1971, in the dry season



Obscure quake risk

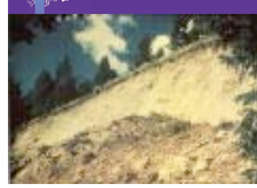
- 1994 Northridge quake
  - Lots of dust floated out over LA
  - Valley Fever
    - Fungus spores in near-surface dust
  - Incidence of Valley Fever higher by a factor of ten in 8 weeks after quakes
  - An extra 5-10 deaths
  - Raised death toll from Northridge
  - First self-referenced Google result

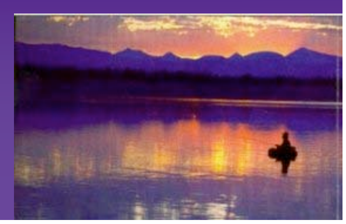
http://landslides.usgs.gov/html_files/nlic/California/Jibson/valleyf.htm

15 m high mudflow:

Hebgen Lake 1959 quake

- M 7.5
- Landslides
- Caused seiches (waves in lake)





Landslide as a dam

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

Path of Peru slide

Picture in previous figure

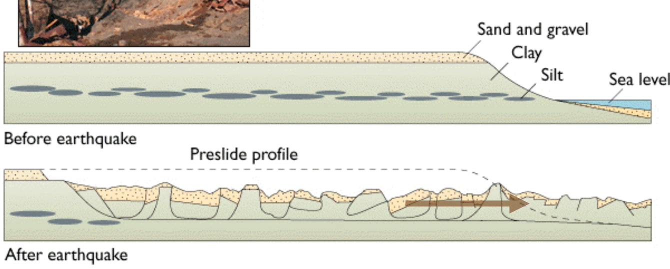
Turnagain Slide, Anchorage
1964 Alaska

- 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

Turnagain - one edge

Yanev, 66

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

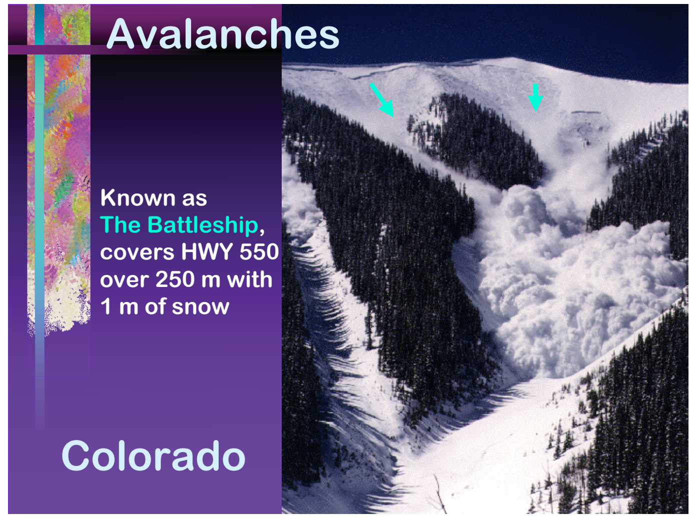


Before Turnagain slide
and before buildings

Note that area had slides before

Ocean


After Turnagain slide


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


75 mm mountain howitzer
Battling avalanches


Another gun