This lecture

- Dams
- Buildings
- Proper response to a quake
- Real odds in a quake

Manmade hazards

- Certain structures present a hazard to neighboring or nearby buildings, including
  - Dams and reservoirs
  - Dikes and levees
  - Water tanks
  - Neighboring buildings

Dams and reservoirs

- Dams are structures most hazardous to populated areas
- Heavily populated urban areas like LA and SF contain many small reservoirs within city limits

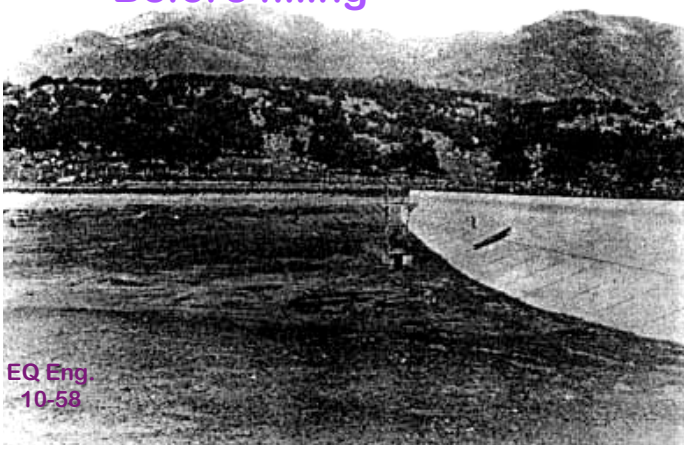
Dam collapses

- Sheffield Dam in Santa Barbara
- St. Francis Dam near Saugus
- Baldwin Hills Reservoir
- Van Norman Dam near San Fern.

Sheffield Dam

- Sheffield Dam failed in Santa Barbara earthquake of 1925 (M7)
  - 250 m long, 5 m high, 30 million gallons
  - 100 m of dam liquefied and washed down
  - flooded lower Santa Barbara

Before filling

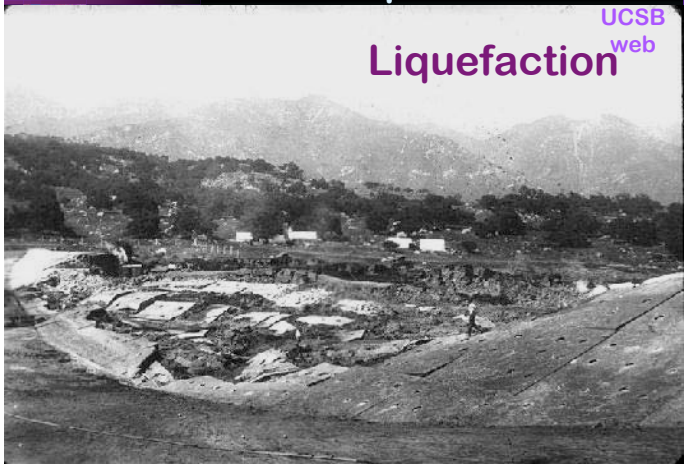


EQ Eng
10-58

Ex-dam after quake

UCSB web

Liquefaction



St. Francis Dam

Keller, 3-24

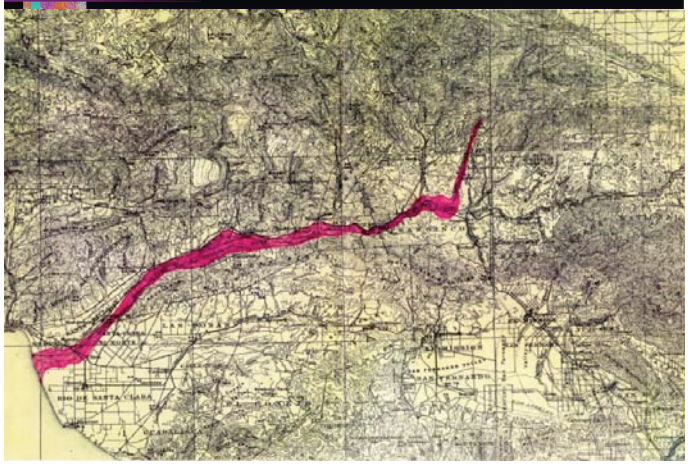
St. Francis

- St. Francis Dam near Saugus, CA
  - Failed March 12, 1928 at night
  - 500 people killed, $10 million is damage
- Problem complicated
  - Rocks softened when wet
  - Fault zone carried water
    - Dam sprung a leak
  - Then softened rock slipped, dam failed

St. Francis after failure

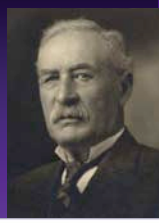
Keller, 3-24

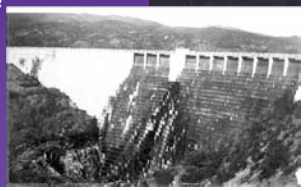
Flooded area

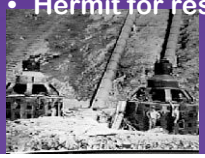


Mulholland's downfall

- Chronicled in movie "Chinatown"
- Built the dam through intrigue
- Just hours before collapse
  - He visited dam
  - Saw water streaming out
  - Advised ignoring the problem
- Crucified after failure
- Hermit for rest of life







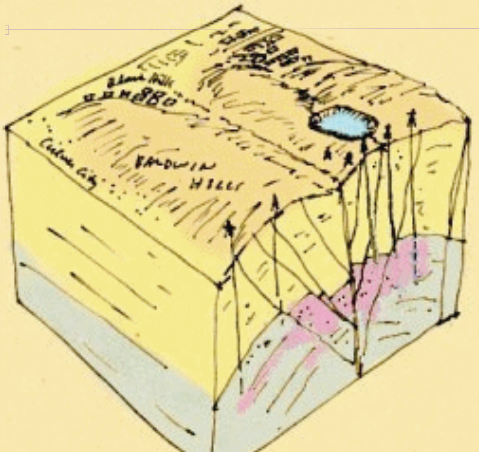
Mulholland told the Coroner's Inquest that he **"only envied those who were killed"**

•He went on to say **"Don't blame anyone else, you just fasten it on me. If there was an error in human judgment, I was the human".**

Coronor's inquest

Another dam collapse

- Baldwin Hills Reservoir
  - December 14, 1963
  - failed after weakening by several years of creep on Newport-Inglewood fault
  - Constructed in 1951, but built on the fault zone responsible for 1933 Long Beach earthquake
  - Claimed 5 lives despite quick evacuation of area below reservoir, 2 hours of warning, $15 million in property damage
  - Fault creep may have been related to withdrawal of oil underneath from 1923 to 1963



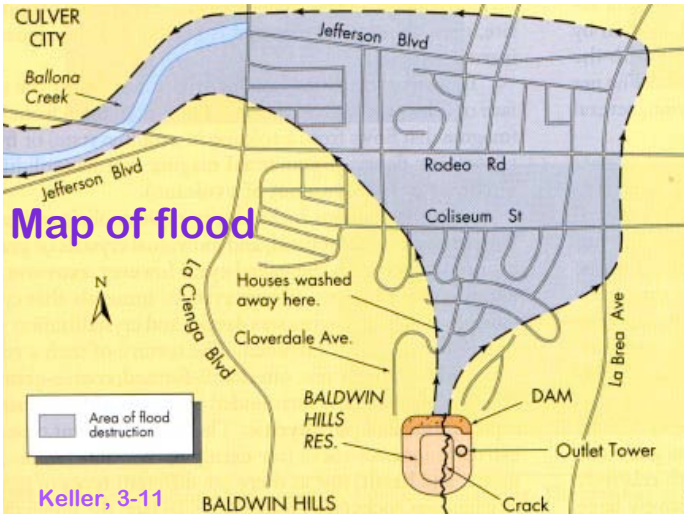
Baldwin Hills Dam failure

Breach in dam

Keller, 3-11

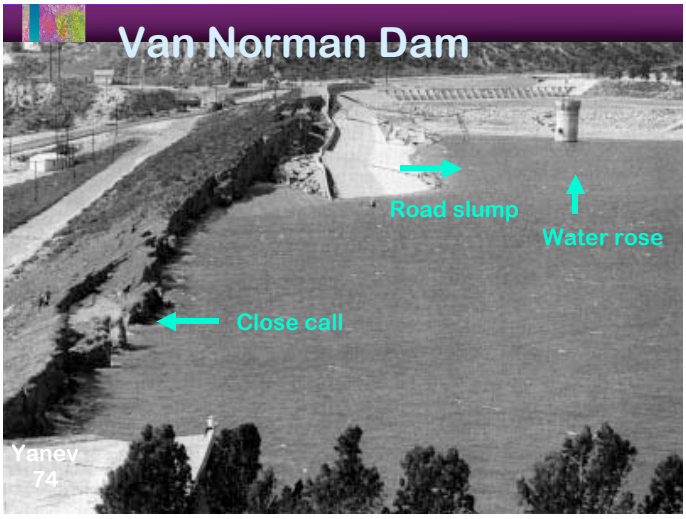
View of dam after failure

Keller, 3-11



Near collapse of dam

- Lower Van Norman Dam in San Fernando earthquake of 1971
  - Constructed in 1915, reinforced several decades later
  - Quake shook upstream surface into reservoir, left only 5 ft margin above water
  - Threatened 12 square miles with 80,000 sleeping residents



Tanks

- Heavy and may be old and weak
  - Thin-walled and flimsy
- May collapse during quakes
- Several kinds
  - Water
  - Oil
  - Wine

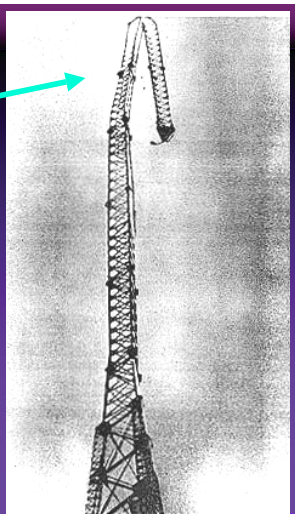
Nogales Bay, 1906

Ex-elevated water tank
1952 Kern County tank

100' tall, 100,000 gallon

Yanev, 76

Seattle radio station KJR



Olympia quake of 1949

EQ Eng, 192

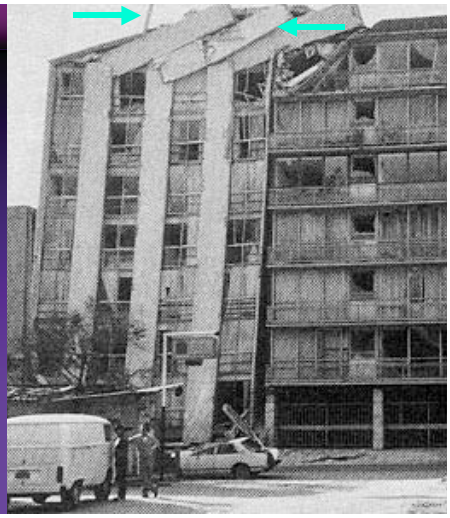
Neighboring buildings

- Two adjacent buildings usually respond to earthquake vibrations in different ways and therefore may pound against each other
  - especially bad for higher building at roof level of lower one
- Or one may fall on another
- Or corner buildings may flop out

Santa Cruz 1989

Yanev, 78

Mexico City 1985



Yanev, 80

Hit by neighbor's bricks

Yanev, 79

Santa Cruz 1989

Corner building flops out

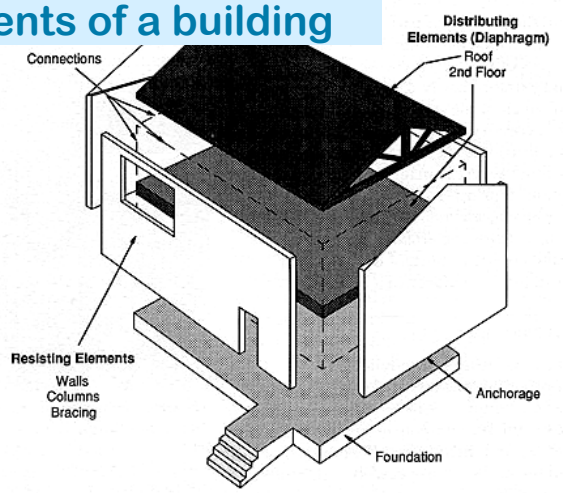
Yanev, 81

Marina district, 1989 Loma Prieta quake

Structural components of a building

- Distributing elements
  - are horizontal
  - consist of floors and roof
- Resisting elements
  - are vertical
  - consist of walls, columns, bracing
- Foundation
- Connections

Elements of a building



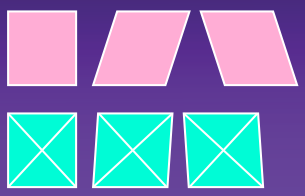
Yanev, 84

How do earthquake forces affect buildings?

- Structural elements designed to support weight
  - of building, furnishings, occupants
- Therefore, vertical forces of earthquake are usually resisted effectively by buildings
- However, lateral bracing needed to resist horizontal forces (ground shaking or wind)

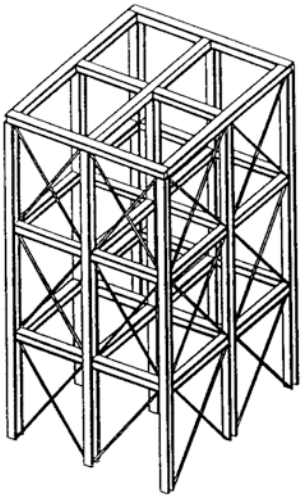
How bracing reduces lateral motions

Shaking in earthquake ⟷



- Reduced lateral motion results in smaller accelerations and less damage to building and contents

Diagonal bracing



Yanev, 86

Shear walls being built

Earthquake resistance

- Wood frame (and with stucco)
- Unreinforced brick
- Concrete block
- Reinforced brick — Residential
- Unreinforced stone and adobe
- Steel frame
- Concrete frame — Commercial
- Concrete shear wall
- Concrete tilt-up

Wood-frame buildings

- If well-built, safest structures due to lightness and flexibility of wood
- May still have damage if
  - On unstable ground
  - Not well fastened to foundation
  - Inadequate lateral bracing
  - Poorly maintained
  - Weak foundation

Plywood sheathing

Yanev 91

Concept of soft story

- Large openings reduce shear strength of walls
  - openings include garage, windows, doors
  - often but not always at ground level

Soft-story construction

Yanev, 112

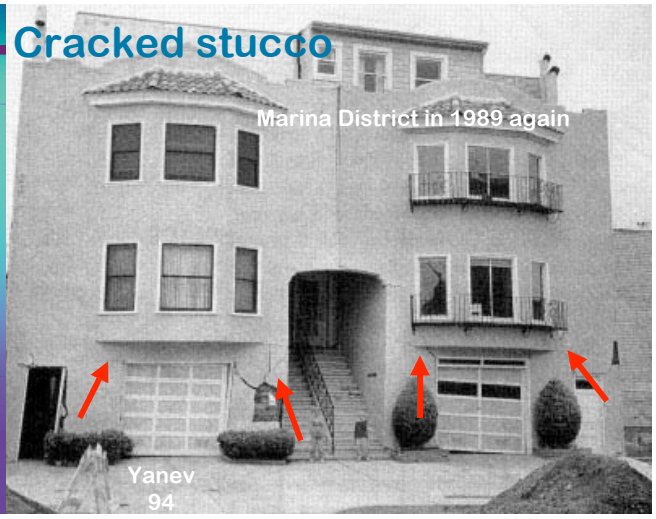
Irreparable

Yanev, 112

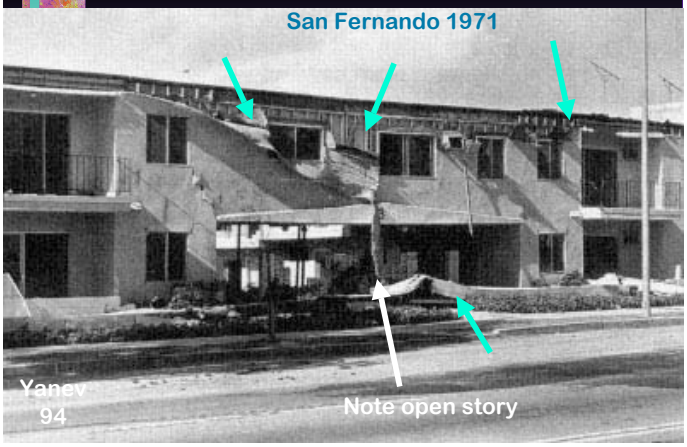
Wood-frame with stuccoed walls

- Stucco adds weight, therefore makes building weaker
- 1 " of stucco strong as 1/4 " plywood
- Stucco damage is around openings where stresses concentrate

Cracked stucco



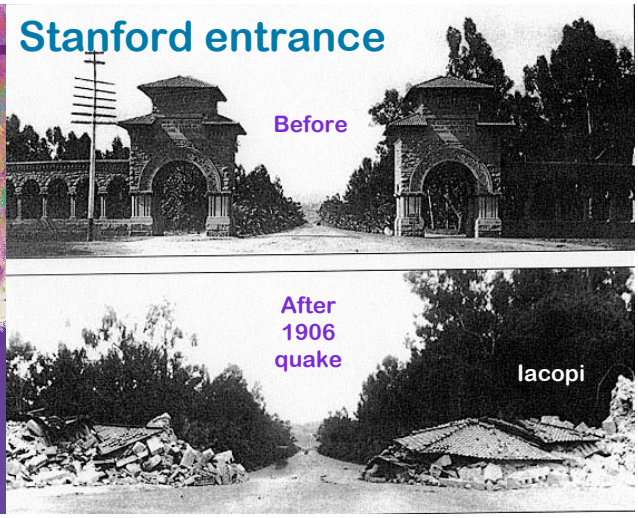
It wasn't supposed to do this



Unreinforced brick buildings

- Most dangerous type in earthquake
  - suffer most severe damage
  - cause majority of deaths
- Difficult and costly to repair and strengthen
- 9500 brick buildings in Los Angeles area

Stanford entrance



Why are they so dangerous?

- Brick is heavy and inflexible
- So lateral motions create large inertial forces that crack mortar (usually weak).
- Bricks can separate, walls collapse unless wood-frame interior walls can hold up building.

1933 Long Beach

Yanev 98

Held up by wood frame

Examples of problems with brick structures

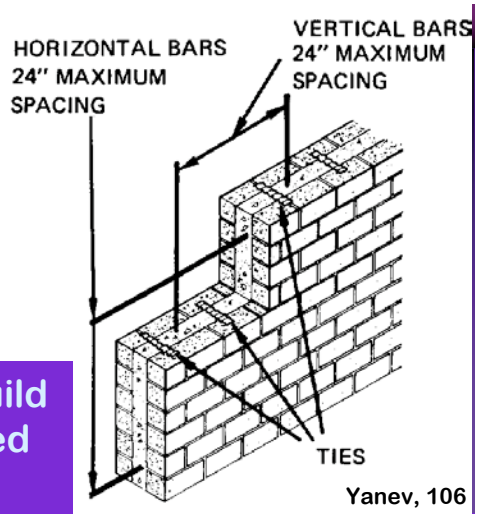
- In 1952 Kern Co. quake, only 1 of 71 brick buildings in Bakersfield survived undamaged
- In 1983 Coalinga quake most of 90 brick buildings removed
- Most of 64 killed in 1971 San Fernando died in collapse of a brick hospital
- Most of deaths in 1989 Loma Prieta not due to collapsed freeway were caused by falling bricks

Hard to reinforce URM buildings

- Strengthening is inhibited by
  - High retrofit costs
  - Trend toward historical preservation
  - Budget cutting
  - Lack of landlord concern

Not a retrofit strategy

How to build reinforced brick



Yanev, 106

Façade trouble

Note mismatched building heights

5 killed in parked cars

Yanev, 102

Clay tile disaster

Veteran's Hospital, San Fernando

Yanev, 106

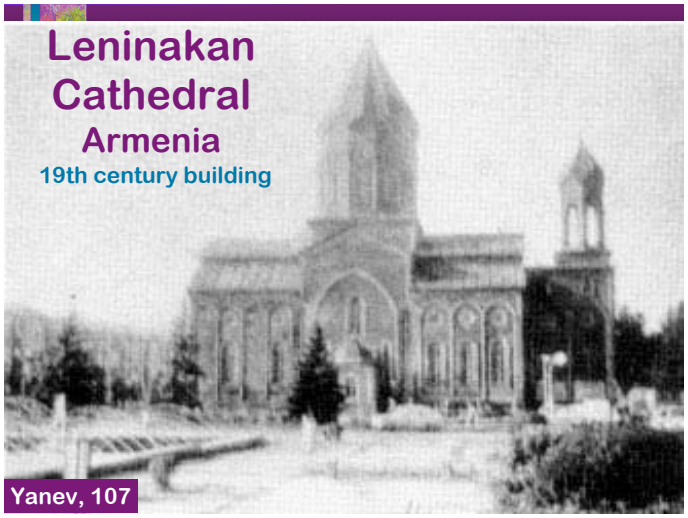
Unreinforced stone and adobe

- Have practically no strength for resisting lateral forces of earthquakes
- Difficult to strengthen
  - Not feasible except for historical monuments
- Many such buildings in Central and South America, Southern Europe, and Asia
- Responsible for numerous casualties

Leninakan Cathedral

Armenia

19th century building



Yanev, 107

Cathedral, after 1988 quake

Unreinforced stone

Yanev, 108

Commercial buildings

- Steel-frame buildings
- Unreinforced masonry
- Concrete-frame
- Concrete shear wall
- Concrete tilt-up

Welds in steel frames - serious business

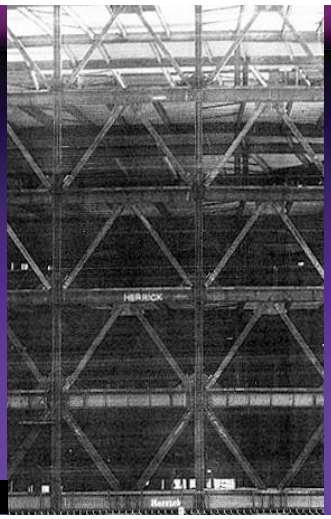
- Example: St. John's Medical Plaza in Santa Monica
  - 5-story office space and exam rooms for doctors built in 1986
- Damaged in 1994 Northridge quake
  - No visible problems
  - Inside walls, vital welds were broken
  - $10,000,000 lawsuit

The building, a lawyer, and some bad welds

LA Times

The type of frame that has trouble in LA

The San Bernadino Regional Hospital Complex at Colton

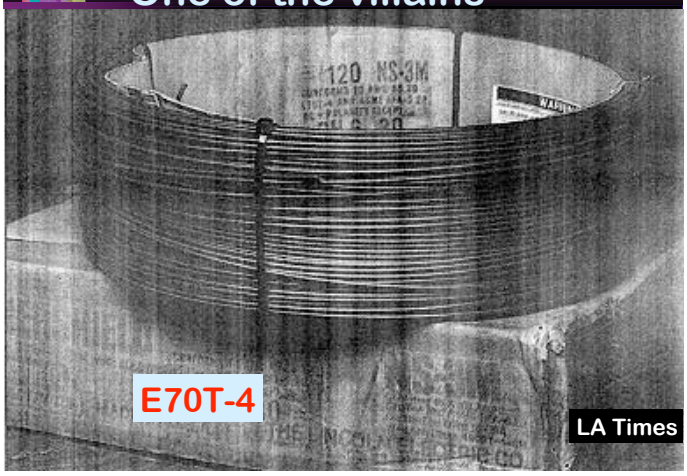


LA Times

Larger issue

- Metal used in welding is weak
  - "120" or "E70T-4"
  - This metal has been used across western US for decades
  - 1500 LA buildings use this welding metal
  - 150 had cracks in Northridge
  - Which was only an M7 quake
- Was outlawed in LA in July 1996
  - For new construction only, of course

One of the villains

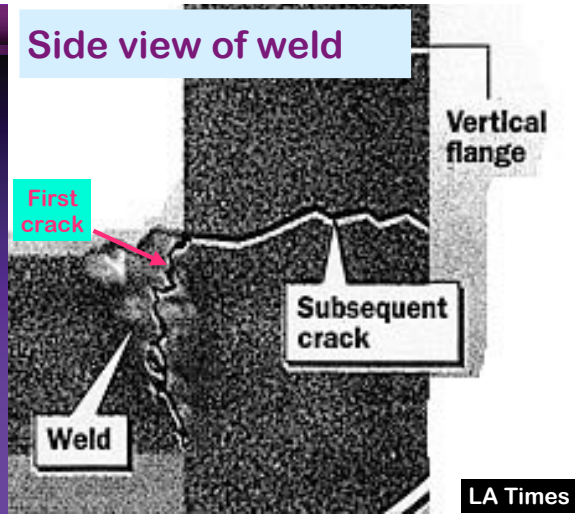


LA Times

Technical details

- About as strong as other welds
- But, 1/4 as resistant to cracks as other welding metals
  - Difficult to measure
- Can be applied from thicker wire at higher temperature
  - So using this metal speeds up welders by 20-30%
  - Which saves money

Side view of weld



LA Times

Whose fault was (is) it?

- Company that made it (Lincoln)
  - Know welding material best
- City of LA
  - Style of construction should have been outlawed
- Engineers that designed buildings
  - Their job to make building that works
- Welders who assembled buildings
  - Establishes standards for welding

History is murky

- Lincoln people claim not to know what metals they tested and when
- University researchers paid by Lincoln also developing faulty memories
- Easy for LA to claim ignorance

Concrete-frame structures

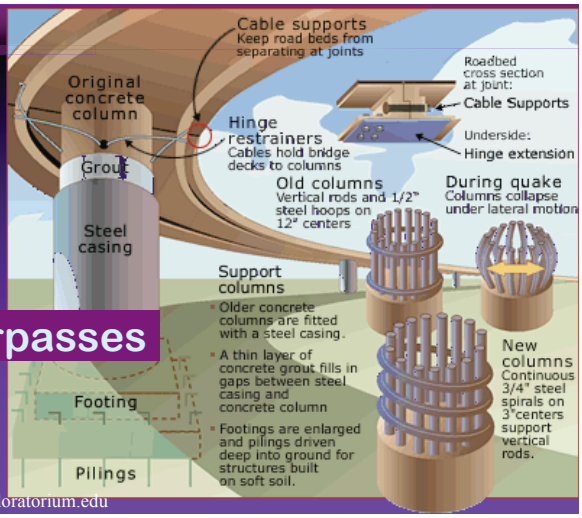
- Second most dangerous structure
- Uses concrete beams and columns in same manner as steel beams are used on steel frame buildings
  - but more brittle and **much heavier**
- **Cypress freeway** (I-880) had this type of construction
- Many collapsed in **Mexico City** in 1985 M~8 quake (10,000 deaths)

I-880 viaduct collapse in 1989 Loma Prieta

Yanev, 110

Concrete frame

Overpasses



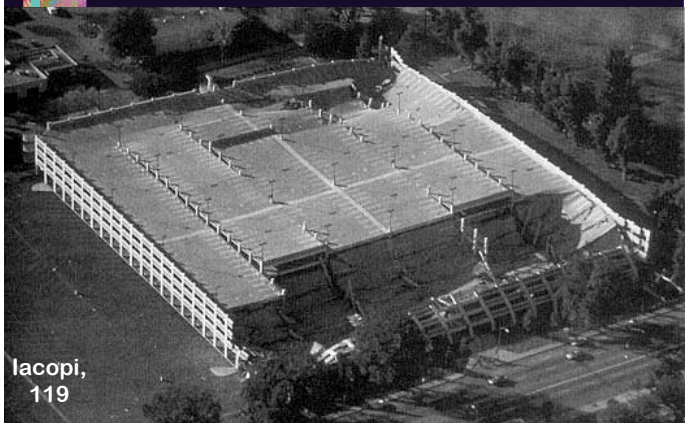
www.exploratorium.edu

Concrete frame building in 1985 Mexico City quake

Yanev, 111

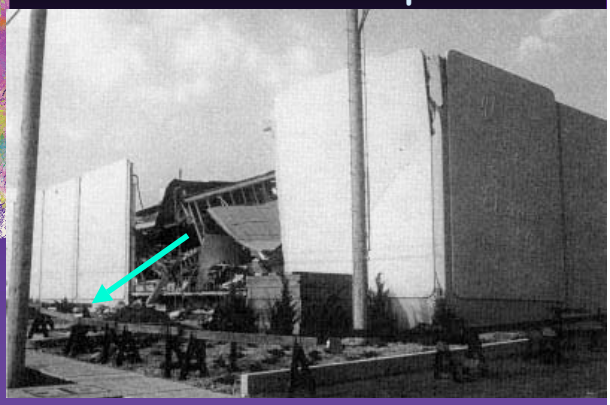
Note soldiers removing debris

Parking garage at Cal State Northridge in 1994 Northridge quake



Iacopi, 119

Tilt-up building collapsed in 1971 San Fernando quake



Yanev, 114

Base isolators

- Decouple motion of building from ground
- Part of major renovation: LA City Hall

http://www.lacityhall.org/Index.htm

Retrofit ingredients

City Hall
1853 - 1883

- 526 isolators / sliders installed
- 52 viscous dampers installed in the basement and 12 viscous dampers installed in the tower
- 30,000 cubic yards of concrete
- 16 million pounds of reinforcing steel
- 35,000 cubic yards of earth excavated
- $300 million

Base isolators

In action - 21” of motion

Viscous dampers

The “moat” allows building to float

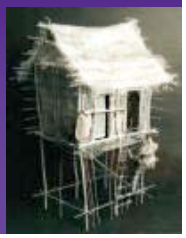
Old 10th floor ceiling

New 10th floor ceiling

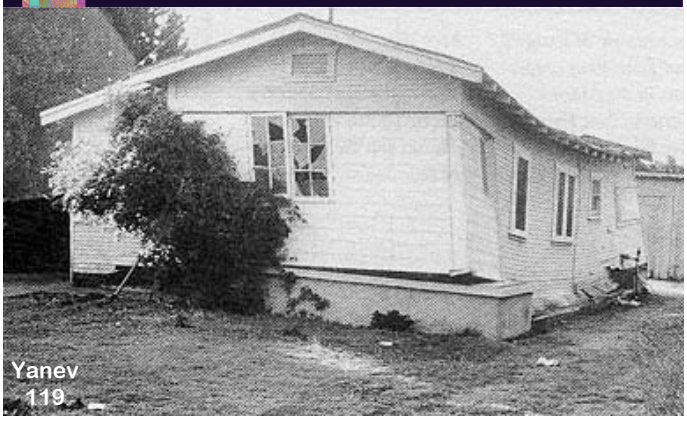
More steel

Particular problems

- Foundations
- Cripple walls
- Stilts and pilings
- First-floor garages
- Parapets
- Chimneys

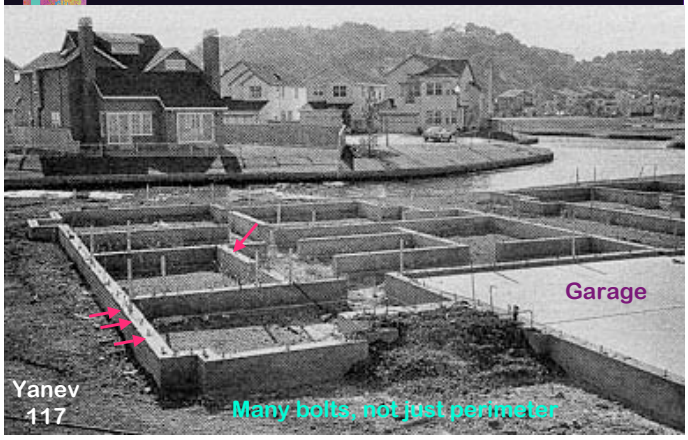


Older house simply resting on foundation, not attached to it



Yanev 119

(1) Continuous, tied foundation



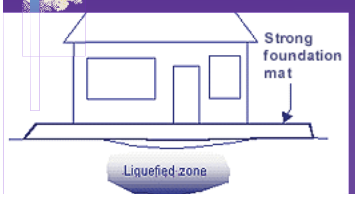
Yanev 117

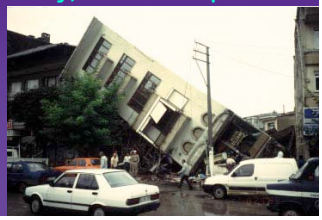
Many bolts, not just perimeter

(2) Mat foundation

- Reinforced concrete slab resting on soil
- Used on soft soil
  - Stronger than continuous, tied foundation
  - Minimizes hazard from differential soil movements by bridging over pockets of loose soil

Turkey, too much liquifaction





(3) Drilled pier foundation

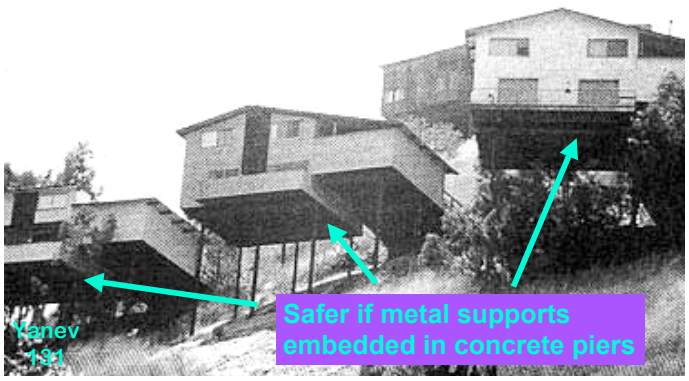
- Steel or concrete pilings set deep in ground
- Used on very soft, weak, or unstable soils

Cripple walls

- Walls of crawl space
  - Short wood walls used to elevate house above ground
  - Access to substructure and utility lines
- Often a weak zone in older house
  - Because a crawl space has only peripheral walls but no interior walls to absorb the force of shaking
  - Badly braced cripple walls 2nd most common weakness of older houses
    - Next to chimneys

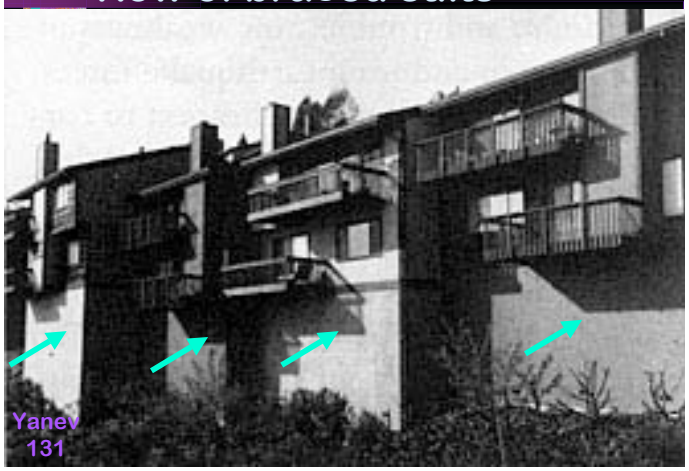
Cripple wall failure in 1971 San Fernando quake

Great views but houses on stilts need special attention



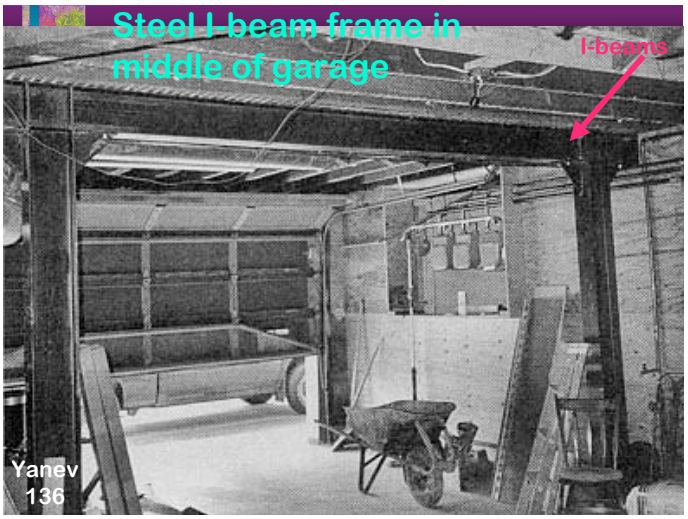
Worst case scenario - Aptos house, in Loma Prieta quake

Row of braced stilts



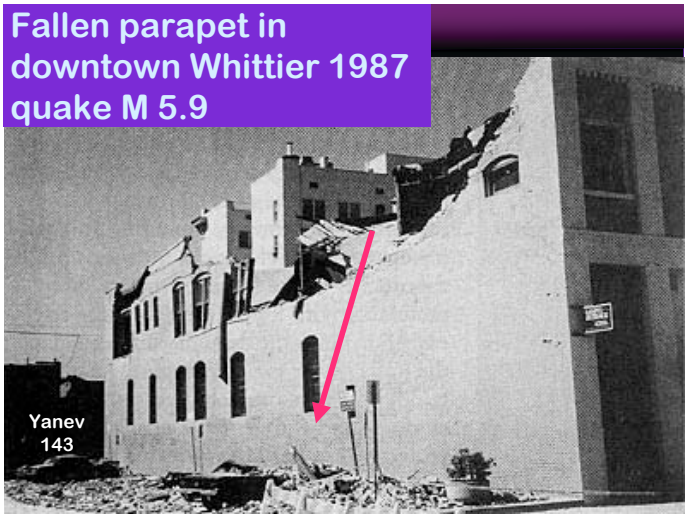
First floor garages

- Garage is large room with only three walls
  - Resists shaking less well
- Remedy is shear bracing
  - Plywood or
  - Steel frame



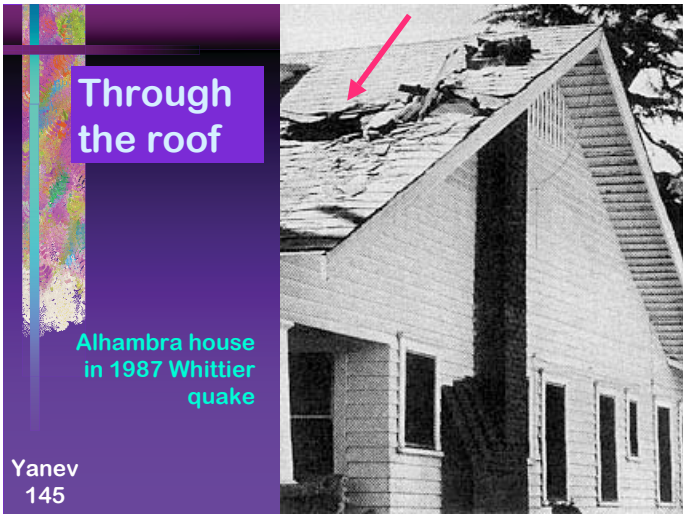
Parapets

- Masonry parapets often first components to fail in quake
  - Building top undergoes highest amplitude shaking
  - Parapet may be poorly connected or weakened by weathering
  - Often out of sight, so poorly maintained
  - Often located above entrances
  - Danger to people running out of building
- May need to be shortened, anchored, and capped with reinforced concrete



Chimneys

- Heavy and high up, subject to strong forces during quakes
- Often damaged
  - 75% of chimneys fell in Bay Area in 1906 quake
- Masonry (brick or stone) chimney pre-1960 is unlikely to be tied to structure adequately and may collapse in quake
  - Can fall through roof or break away from house
  - the higher it rises above roof, the greater is hazard
    - Often breaks at roofline



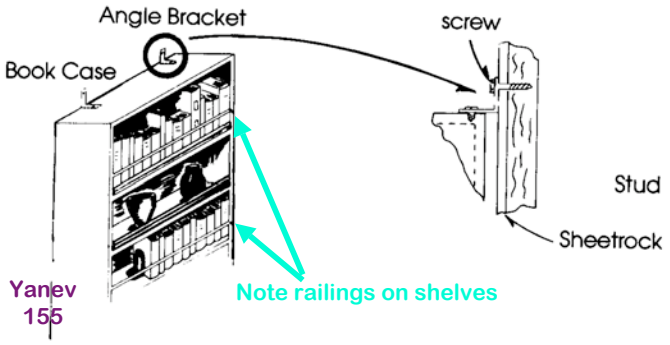
Remedies for chimneys

- Lay 1 inch thick plywood on roof around chimney
- New prefabricated sheet-metal chimneys are light and strong and will not collapse

Rest of lecture

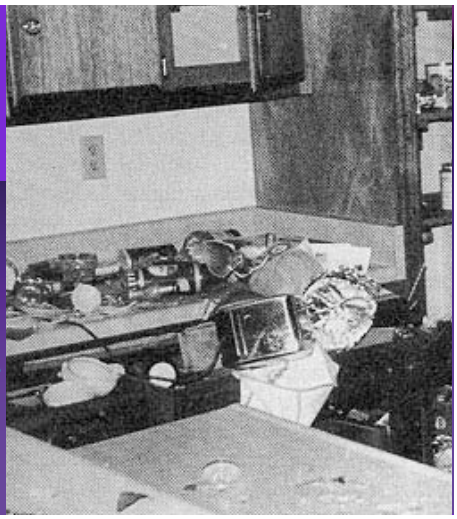
- Interior damage
  - –How to be prepared for quakes
  - –How to behave during quake
- Insurance
- Risk in earthquakes

Anchor tall furniture



Yanev 155

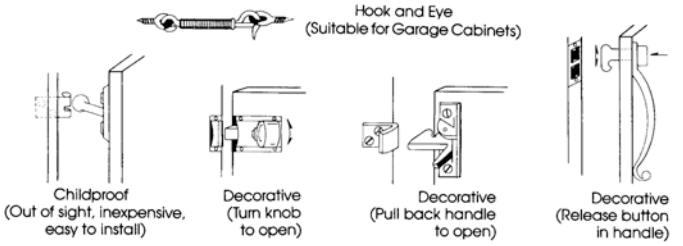
Kitchens - amazing mess



1971 San Fern, mine looked worse in 1989

Yanev 158

Use positive latches

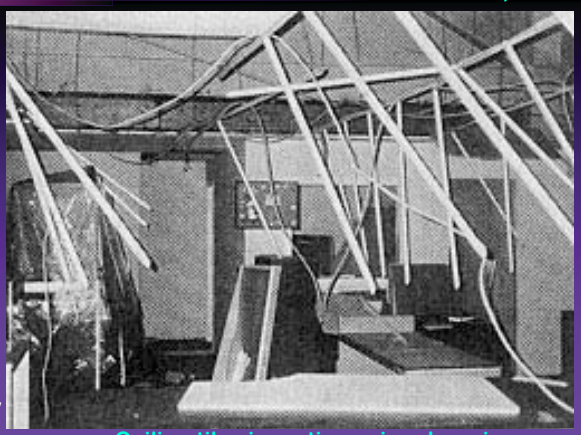


Yanev 157

For fragile valuables and dangerous chemicals

Places of work

Whittier, 1987



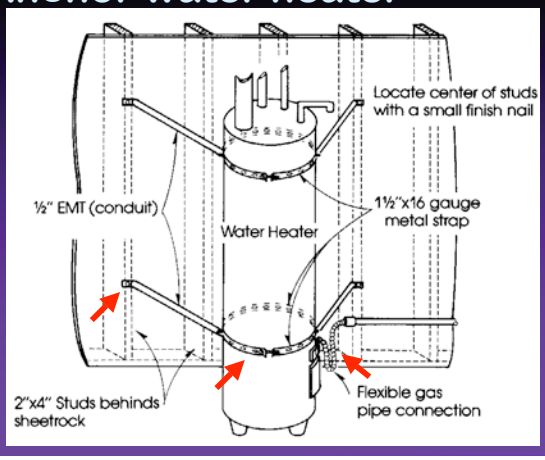
Yanev 159

Ceiling tiles in motion, wires hanging

Planning for quakes

- Consider safe and dangerous places in your house
- Consider how to get to exits
- Learn how to shut off utilities
- Anchor water heater

Anchor water heater



Yanev 153

Careful quake planning

- School evacuation
- Adequate supplies
- Pets
- Outside communication coordinator
- Skills of neighbors

Adequate supplies

Wax Baywatch figures

- Water
  - Water heater and toilet tanks
    - Purification tablets helpful
- Food
  - Usually several day's food around
  - Use refrigerated food first
- First aid kit
  - And a book on first aid
  - Useful to take first aid course as well
- Fire extinguisher
  - Needs periodic checks or servicing

During quake

- Get under table or go to doorway
- Avoid big windows and chimneys
- Do not rush outdoors or into stairwells

Olive View Hospital San Fernando quake, 3 out of 4 fell over

Once quake stops

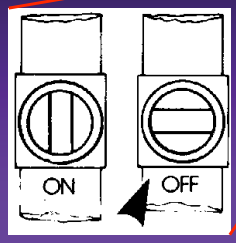
- Walk slowly outdoors
- Stay in open areas
- Only re-enter safe buildings
- If in a car
  - Stop in an open area
  - Stay in car a while

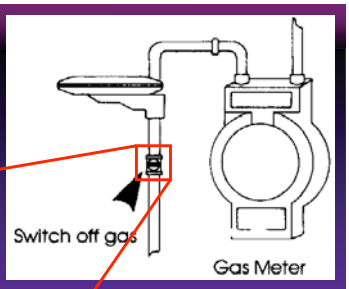
Seatac control tower

After quake

- Care for injured people
- Check
  - Gas lines
  - Electric lines
  - Then water lines

Gas line shut-off

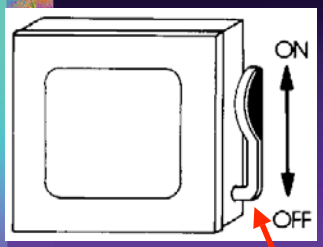




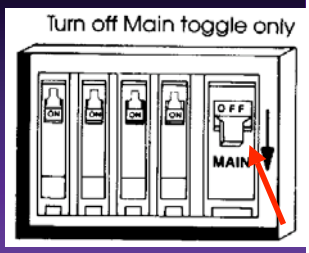
Just takes a wrench

Yanev 152

Electrical turn-off



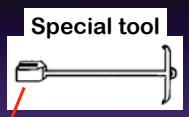
Main fuse box

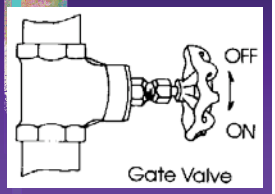


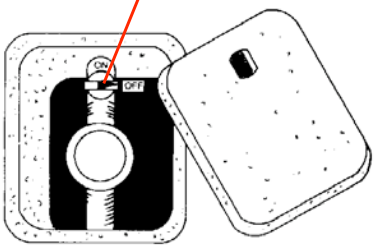
Circuit breaker

Yanev 152

Water shut-off

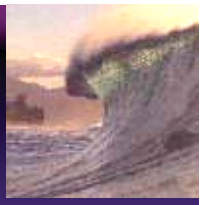






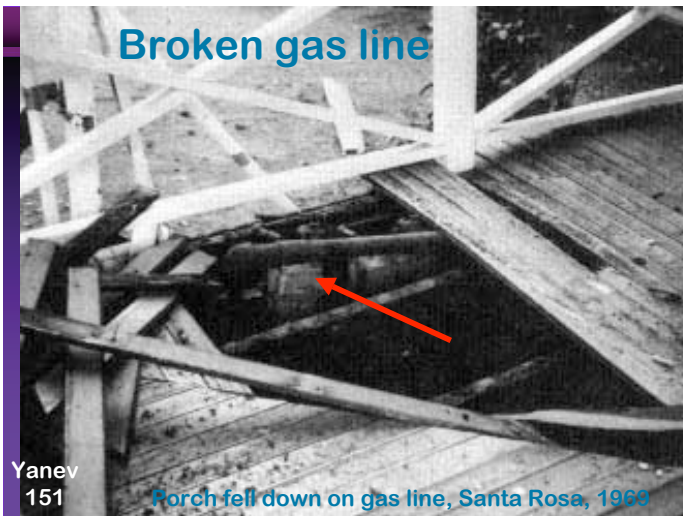
Yanev 152

Then



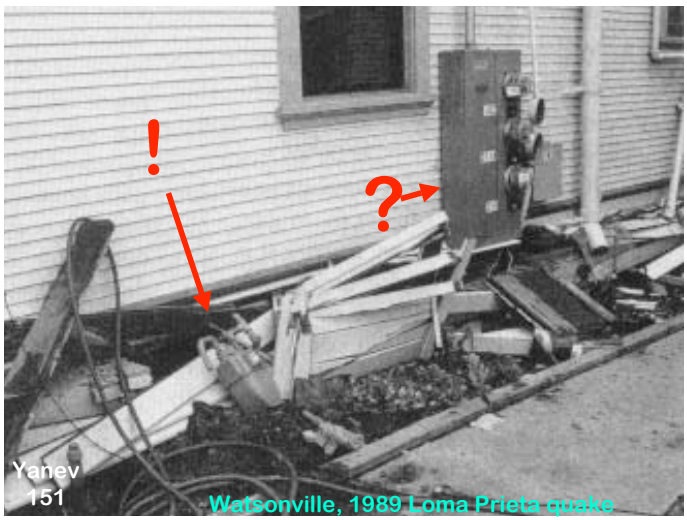
- Remember
  - Try to minimize phone use
  - Tsunamis are possible
  - Aftershocks are certain and may be dangerous
  - Landslides are possible

Broken gas line



Porch fell down on gas line, Santa Rosa, 1969

Yanev 151



Watsonville, 1989 Loma Prieta quake

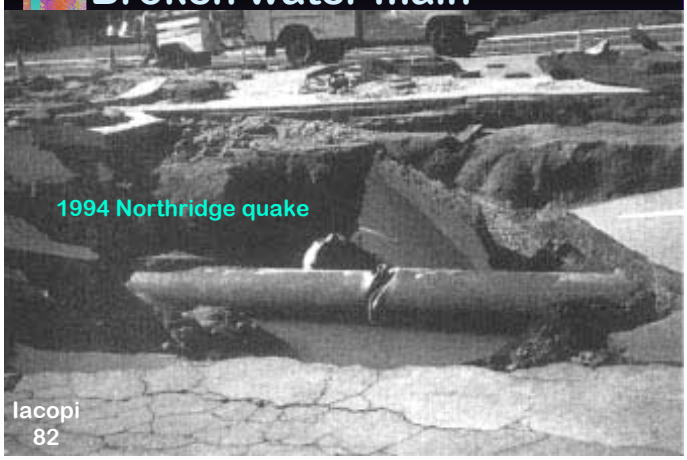
Yanev 151

Gas leak ignited

Watsonville, 1989 Loma Prieta quake

Yanev
151

Broken water main



Iacopi
82

Disrupted power relay

Iacopi
104

1971 in Sylmar

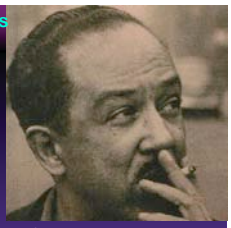
Earthquake insurance

- No simple strategy
- Changing state regulations
- Deductibles
- Vulnerability of insur. co.
- FEMA (Federal Emergency Management Agency) as back-up for insurance
- Should make house safe, in any case

Real risk from quakes

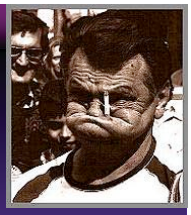
- Standard unit of risk
  - 1 in a million chance of death in a year
  - In other words, a person loses 30 minutes of life expectancy
- Math
  - 30,000,000 sec in a year
  - 1/1,000,000 risk
  - Average person has 60 yr life ahead
  - Thus, cost of 30 minutes on average

Example


Langston Hughes

- Cigarette smoking
  - Each cigarette adds about 1 in a million chance of death
  - So smoking a cigarette shortens life, on average, by half an hour, or several times longer than the cigarette takes to smoke

1 in a million risks



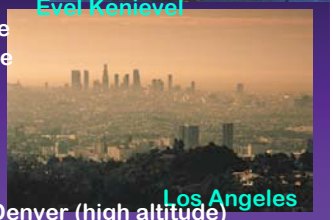
- Smoking a cigarette
  - Cancer, heart disease
- Drinking half a bottle of wine
  - Cirrhosis of the liver
- An hour in a coal mine
  - Black lung
- Three hours in a coal mine
  - An accident

Wilson, 1979

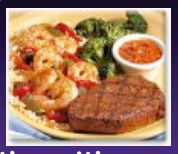
More


Evel Knievel

- Air pollution
  - Living 2 days in NY or Boston
- Accidents
  - 6 minutes in a canoe
  - 10 miles on a bicycle
  - 150 miles by car
  - 1000 miles by jet
- Cancers
  - 6000 miles by jet
  - Living 2 months in Denver (high altitude)
  - 2 months in a stone building (radioactivity)
  - 1 chest X-ray


Los Angeles

Still more 1 in a million risks



- Cancers
  - Living 2 months with smoker
  - 40 tbsp. peanut butter (aflatoxin B)
  - Miami water for a year (chloroform)
  - 30 cans of diet soda (saccharin)
  - 100 charcoal broiled steaks

Risk of dying in a year

All natural causes (age 40)	1 in 850
Violence or poisoning	1 in 3300
Traffic accident	1 in 8000
Quake (living in Iran)	1 in 23,000
Train accident	1 in 500,000
Quake (California)	1 in 2,000,000
Lightning	1 in 10,000,000
Windstorm	1 in 10,000,000