Geologic Hazard Mitigation
(Why It's Safe to Build at LBNL)

Wayne Magnusen, PE, GE

Alan Kropp & Associates, Inc.,
Berkeley, CA

Focus of Presentation

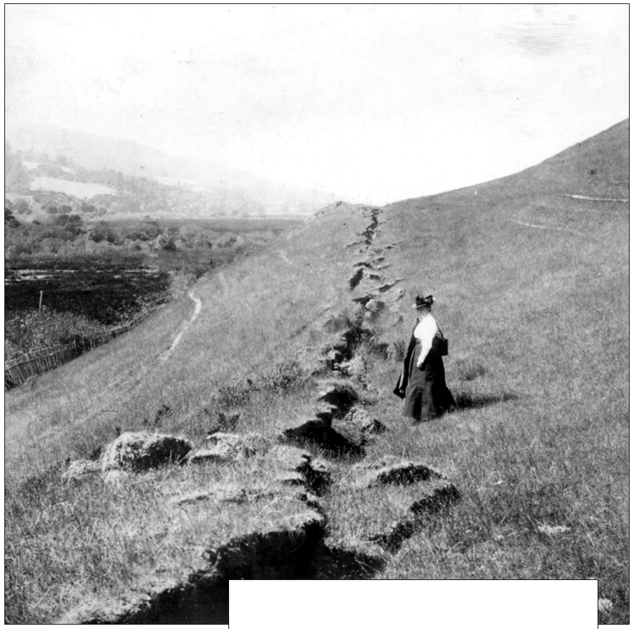
- What Geologic Hazards Look Like
- How Engineers Address Specific Hazards
- Strict Regulations Govern New Projects
- LBNL Appropriately Mitigates Geologic Risks

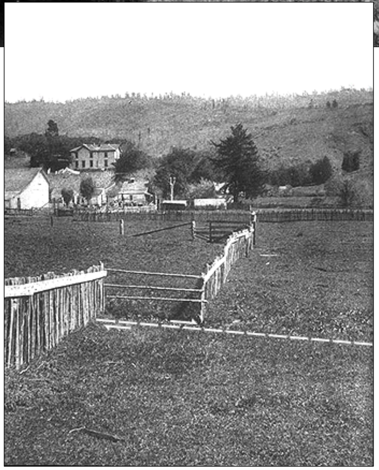
Focus of Presentation

Specific Hazards:

- Fault Rupture
- Ground Shaking
- Ground Failure (Liquefaction)
- Landsliding

Fault Rupture





1906 San Francisco

1992 Landers

Fault Rupture

1972 Alquist-Priolo Earthquake Fault Zoning Act

State Requirement:

No structure for human occupancy defined as a “project” can be built on the trace of an active fault

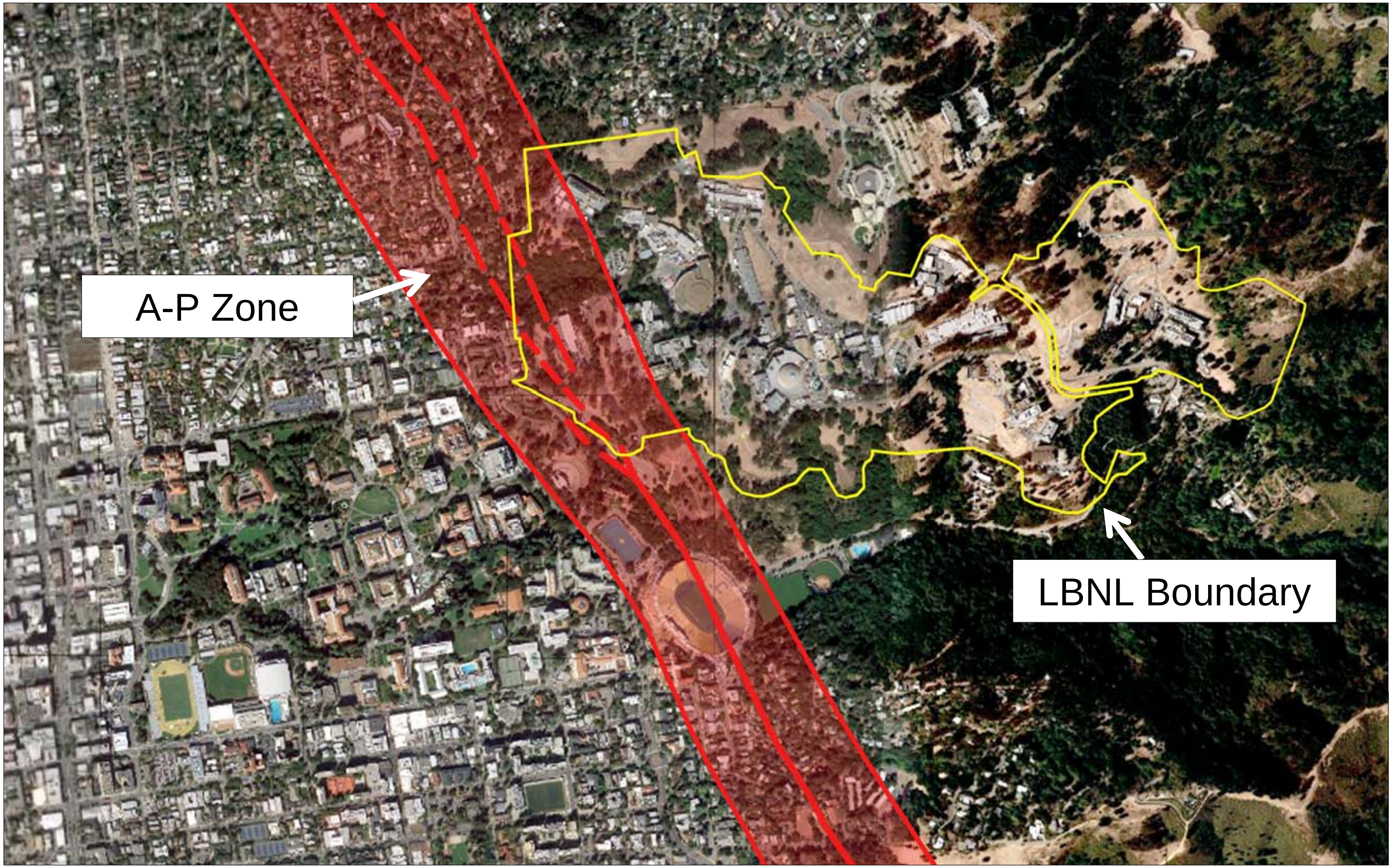
Implementation/Mitigation:

The State defines Earthquake Fault Zones (A-P Zones) around known active faults.

Within the A-P Zones; geologic investigations must be conducted for new projects to check for active faults.

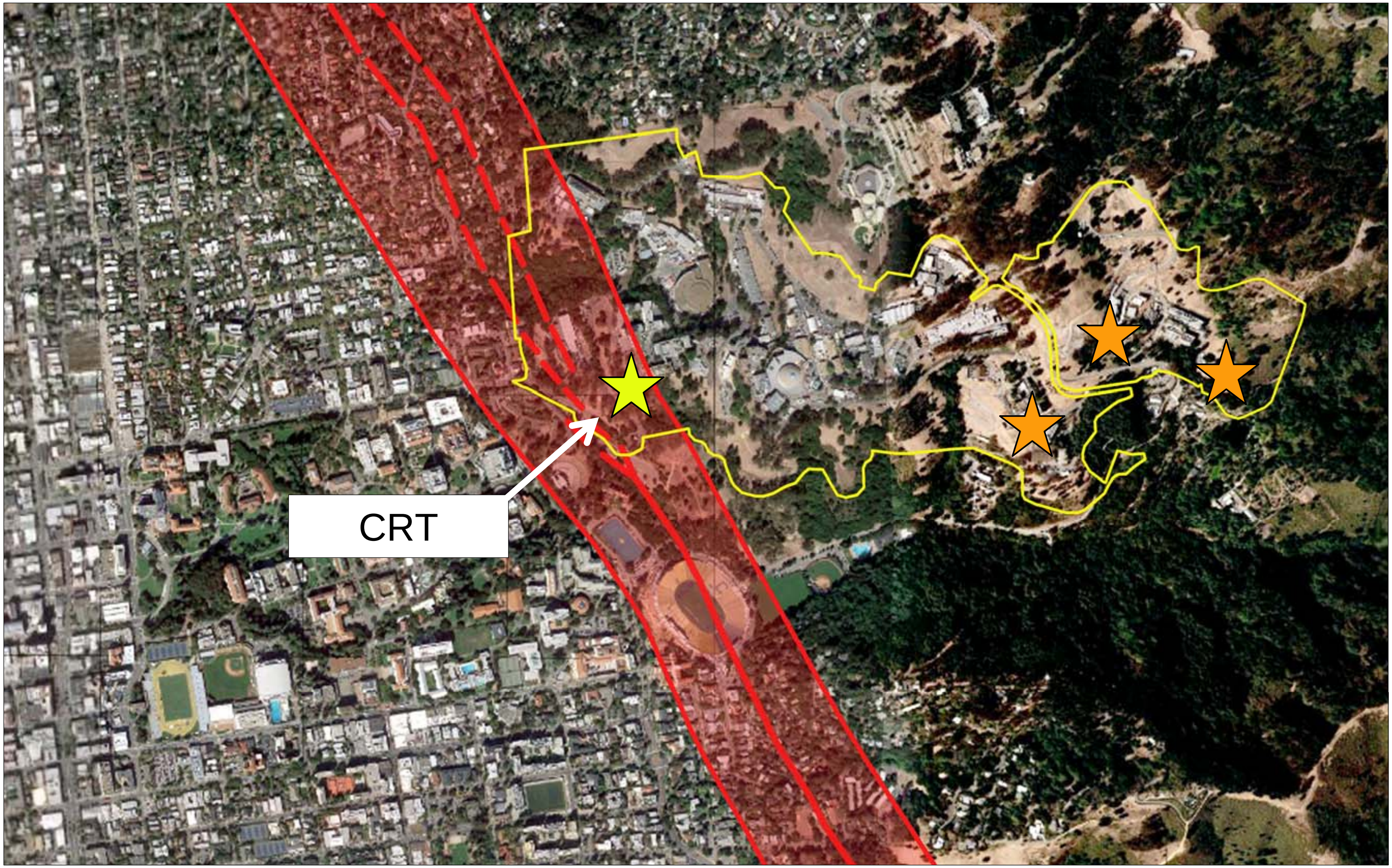
Fault Rupture

1972 Alquist-Priolo Earthquake Fault Zoning Act



Fault Rupture

1972 Alquist-Priolo Earthquake Fault Zoning Act



Fault Rupture

1972 Alquist-Priolo Earthquake Fault Zoning Act

CALIFORNIA GEOLOGICAL SURVEY

NOTE 49

GUIDELINES FOR EVALUATING THE HAZARD OF SURFACE FAULT RUPTURE

GUIDELINES FOR EVALUATING THE HAZARD OF SURFACE FAULT RUPTURE
(Similar guidelines were adopted by the State Mining and Geology Board for advisory purposes in 1996.)

These guidelines are to assist geologists who investigate faults relative to the hazard of surface fault rupture. Subsequent to the passage of the Alquist-Priolo Earthquake Fault Zoning Act (1972), it became apparent that many fault investigations conducted in California were incomplete or otherwise inadequate for the purpose of evaluating the potential of surface fault rupture. It was further apparent that statewide standards for investigating faults would be beneficial. These guidelines were initially prepared in 1975 and have been revised several times since then.

The investigation of sites for the possible hazard of surface fault rupture is a deceptively difficult geologic task. Many active faults are complex, consisting of multiple breaks. Yet the evidence for identifying active fault traces is generally subtle or obscure and the distinction between recently active and long-inactive faults may be difficult to make. It is impractical from an economic, engineering, and architectural point of view to design a structure to withstand serious damage under the stress of surface fault rupture. Once a structure is sited astride an active fault, the resulting fault-rupture hazard cannot be mitigated unless the structure is relocated, whereas when a structure is placed on a landslide, the potential hazard from landsliding often can be mitigated. Most surface faulting is confined to a relatively narrow zone a few feet to few tens of feet wide, making avoidance (i.e., building setbacks) the most appropriate mitigation method. However, in some cases primary fault rupture along branch faults can be distributed across zones hundreds of feet wide or manifested as broad warps, suggesting that engineering strengthening or design may be of additional mitigative value (e.g., Lazarte and others, 1994).

No single investigative method will be the best, or even useful, at all sites, because of the complexity of evaluating surface and near surface faults and because of the infinite variety of site conditions. Nonetheless, certain investigative methods are more helpful than others in locating faults and evaluating the recency of activity.

The evaluation of a given site with regard to the potential hazard of surface fault rupture is based extensively on the concepts of recency and recurrence of faulting along existing faults. In a general way, the more recent the faulting the greater the probability for future faulting (Allen, 1975). Stated another way, faults of known historic activity during the last 200 years, as a class, have a greater probability for future activity than faults classified as Holocene age (last 11,000 years), and a much greater probability of future activity than faults classified as Quaternary age (last 1.6 million years). However, it should be kept in mind that certain faults have recurrent activity measured in tens or hundreds of years whereas other faults may be inactive for thousands of years before being reactivated. Other faults may be characterized by creep-type rupture that is more or less ongoing. The magnitude, sense, and nature of fault rupture also vary for different faults or even along different strands of the same fault. Even so, future faulting generally is expected to recur along pre-existing faults (Bonilla, 1970). The development of a new fault or reactivation of a long-inactive fault is relatively uncommon and generally need not be a concern in site development.

As a practical matter, fault investigation should be directed at the problem of locating existing faults and then attempting to evaluate the recency of their activity. Data should be obtained both from the site and outside the site area. The most useful and direct method of evaluating recency is to observe (in a trench or road cut) the youngest geologic unit faulted and the oldest unit that is not faulted. Even so, active faults may be subtle or discontinuous and consequently overlooked in trench exposures (Bonilla and Lienkaemper, 1991). Therefore, careful logging is essential and trenching needs to be conducted in conjunction with other methods. For example, recently active faults may also be identified by direct observation of young, fault-related geomorphic (i.e., topographic) features in the field or on aerial photographs. Other indirect and more interpretive methods are identified in the outline below. Some of these methods are discussed in Bonilla (1982), Carver and McCalpin (1996), Hatheway and Leighton (1979), McCalpin (1996a, b, c), National Research Council (1986), Sherard and others (1974), Slemmons (1977), Slemmons and dePolo (1986), Taylor and Cluff (1973), the Utah Section of the Association of Engineering Geologists (1987), Wallace (1977), Weldon and others (1996), and Yeats and others (1997). McCalpin (1996b) contains a particularly useful discussion of various field techniques. Many other useful references are listed in the bibliographies of the references cited here.

The purpose, scope, and methods of investigation for fault investigations will vary depending on conditions at specific sites and the nature of the projects. Contents and scope of the investigation may also vary based on guidelines and review criteria of agencies or political organizations having regulatory responsibility. However, there are topics that should be considered in all comprehensive

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CALIFORNIA CONSERVATION
Revised 5/2002

Geologic Trenching Study

Fault Rupture

1972 Alquist-Priolo Earthquake Fault Zoning Act

Conclusions:

1. Only one new LBNL project is within the A-P Zone (the Computational Research and Theory Building).
2. A trenching investigation was performed at the CRT site and no faults were found.
3. Other faults at LBNL that are outside of the A-P Zone are not considered active.
4. New construction at LBNL fully complies with all State regulations and guidelines pertaining to fault rupture.
5. New construction at LBNL appropriately mitigates fault rupture risks.

Structural Damage caused by Earthquake Shaking

1868 Hayward Earthquake
Unreinforced Masonry

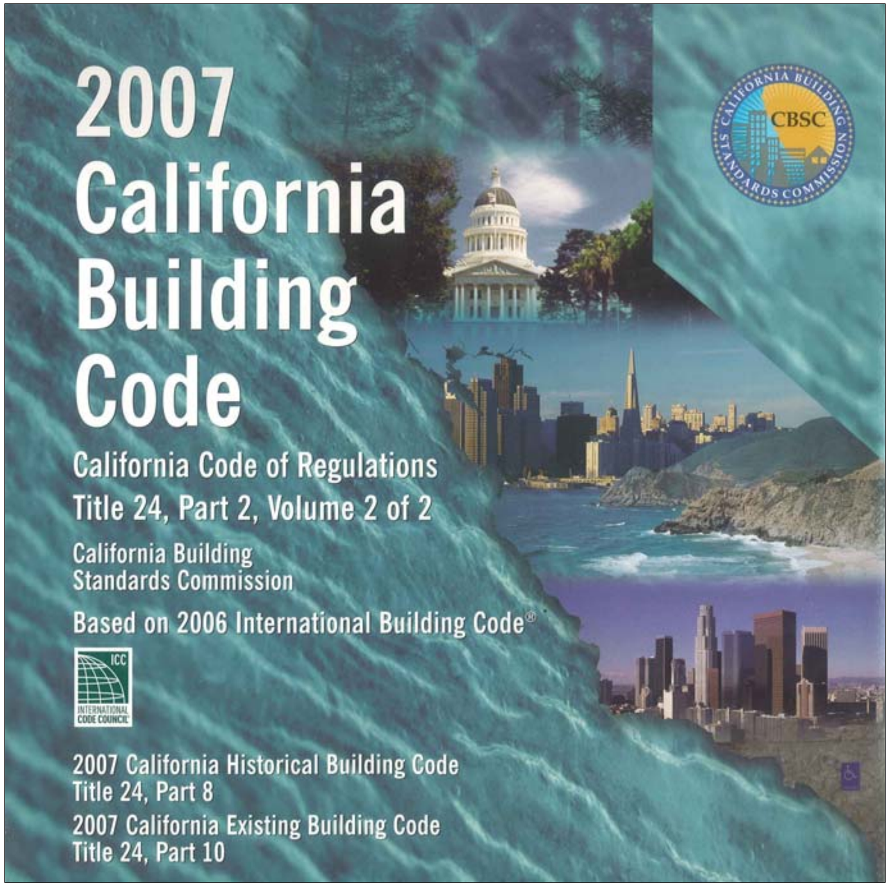
1906 San Francisco Earthquake
Emergence of the Steel Frame

Structural Damage caused by Earthquake Shaking

1971 San Fernando Earthquake
Soft Story

San Francisco
Soft Story Retrofit

Ground Shaking
2007 California Building Code



State Requirement:

Every structure be designed and constructed to resist the effects of earthquake motions.

Implementation/Mitigation:

All new structures at LBNL are designed and constructed in accordance with the stringent seismic requirements of the California Building Code.

Ground Shaking

2007 California Building Code

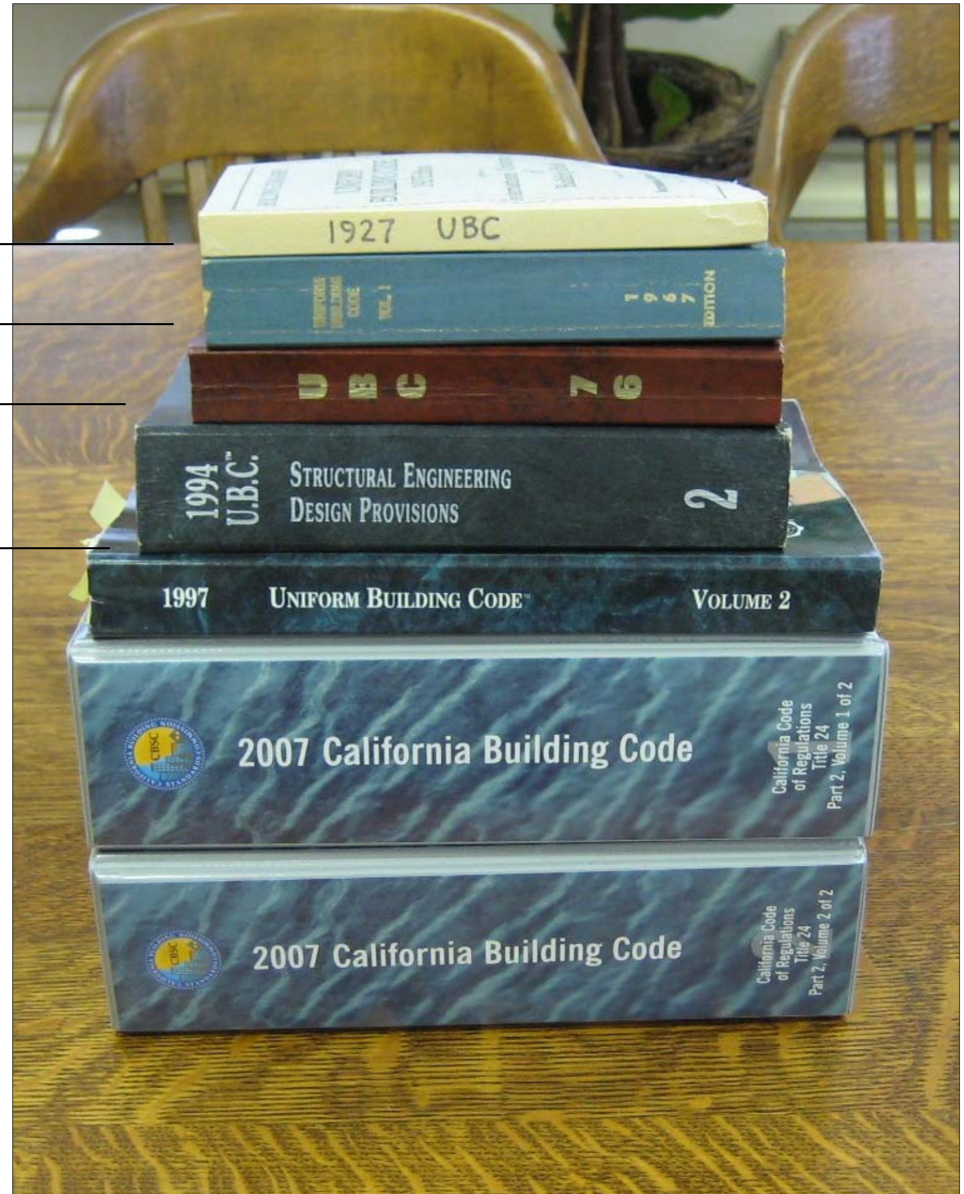
1932 Long Beach

1971 San Fernando

1991 Loma Prieta

1994 Northridge

Current Version of the Code

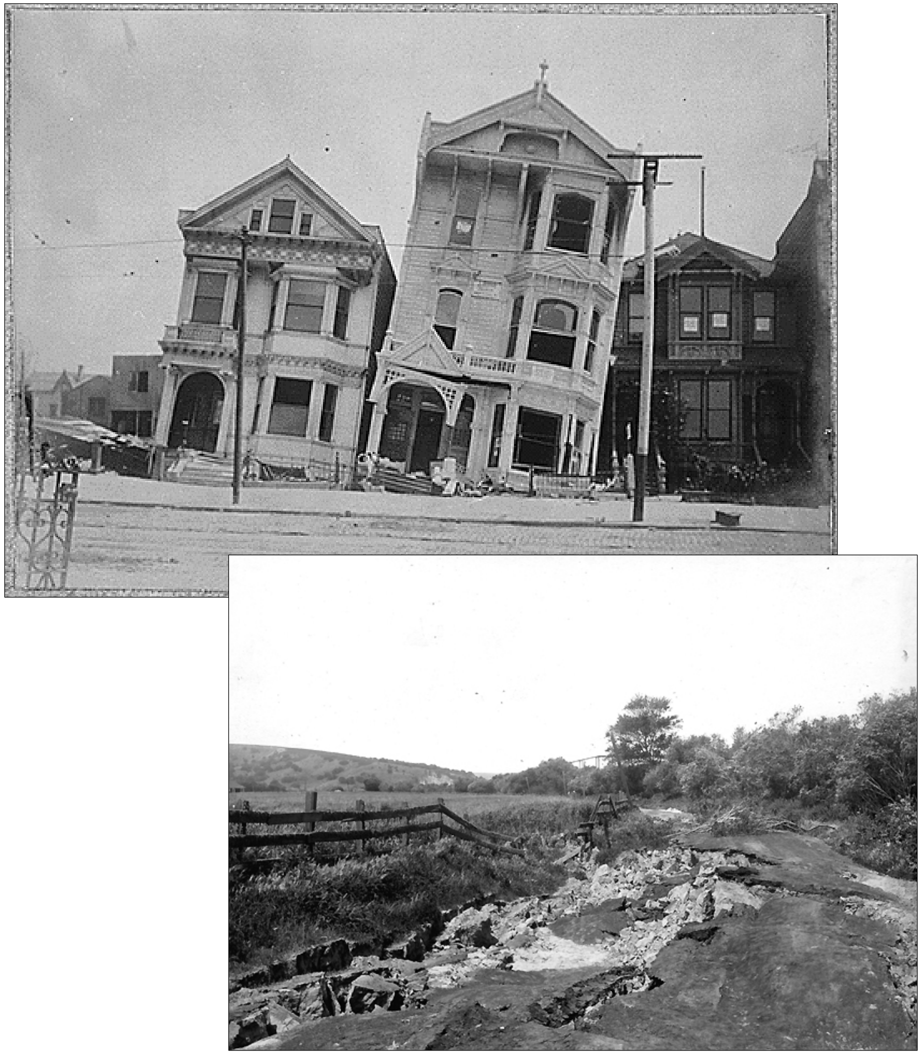


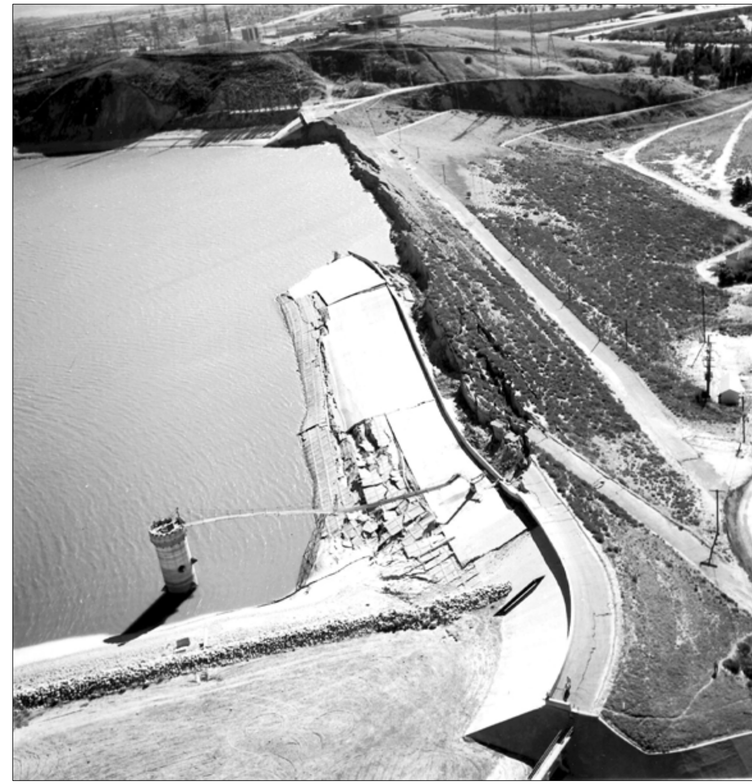
Ground Shaking
2007 California Building Code

Conclusions:

1. Ground Shaking is a hazard that exists throughout much of California. Statewide, this hazard is addressed by the seismic provisions of the California Building Code.
2. All new construction at LBNL fully complies with the current version of the California Building Code, which requires that buildings be designed to resist the anticipated level of ground shaking at the building's location.
3. Predicted levels or earthquake shaking at LBNL are no greater than other areas in Berkeley and may be less than areas close to the Bay where soft soils can amplify ground motions.
4. New construction at LBNL appropriately mitigates ground shaking risks.

Liquefaction





1971 San Fernando Earthquake

1906 San Francisco Earthquake

Liquefaction

1990 Seismic Hazards Mapping Act

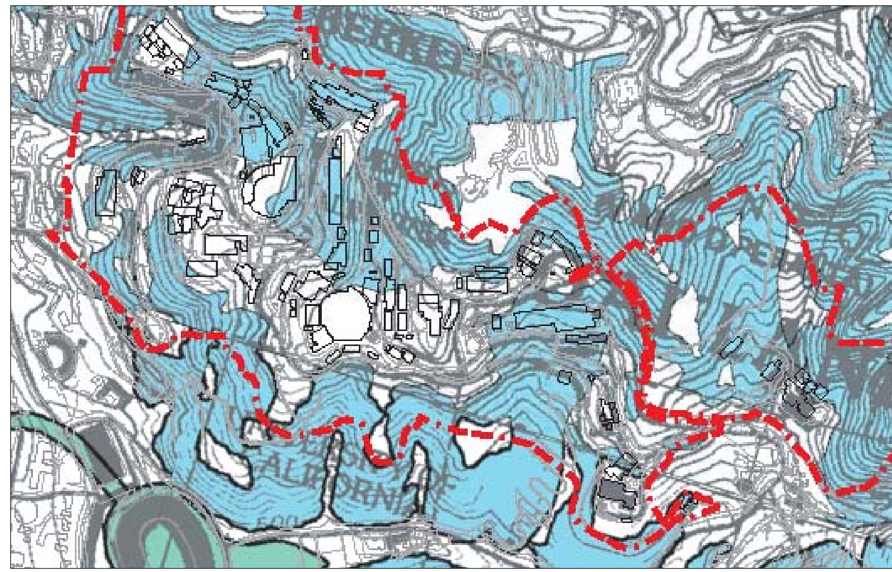
State Requirement:

Recommendations for appropriate mitigation be developed, where needed.

Implementation/Mitigation:

The State defines Zones of Required Investigations where there is a potential for liquefaction to occur.

Within these Zones; geologic investigations must be conducted for new projects to check for hazards and recommend appropriate mitigation.



Zone of Required Investigation for Liquefaction (Green)

Liquefaction

1990 Seismic Hazards Mapping Act

Conclusions:

1. There are no State-defined Zones of Required Investigation for liquefaction at LBNL.
2. Geotechnical and geologic investigations are performed for all new projects at LBNL in which the potential for liquefaction is investigated and assessed.
3. All new construction at LBNL fully complies with the Seismic Hazard Mapping Act and the associated State guidelines that govern liquefaction hazards.
4. New construction at LBNL appropriately mitigates liquefaction risks.

Landslides triggered by Earthquake Shaking

1906 San Francisco Earthquake

Landslides triggered by Earthquake Shaking

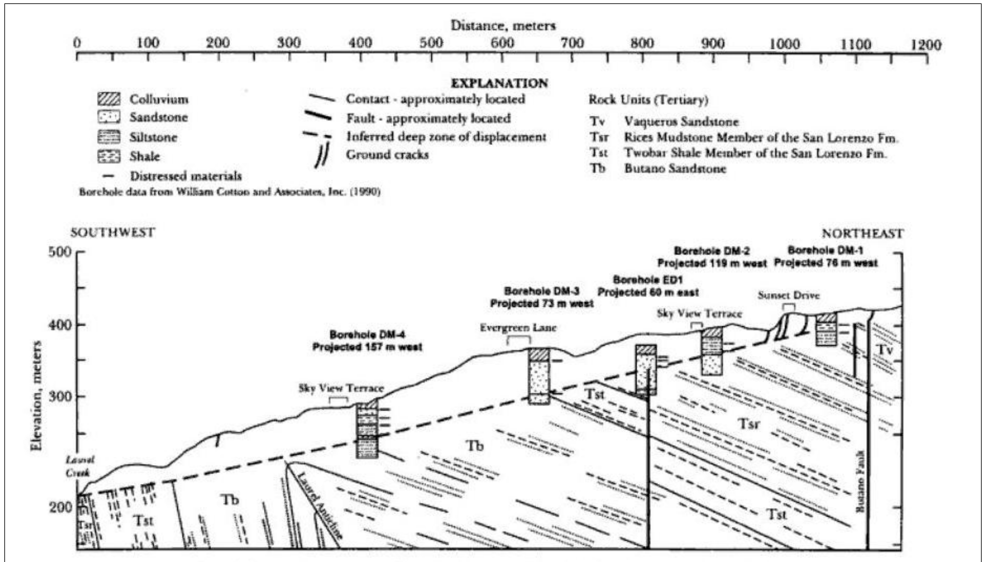


Figure 9. Cross section through Villa Del Monte landslide. Line of section is shown in Figure 8.

1989 Loma Prieta Earthquake

Source: 2002 professional paper by
Keefer (USGS), Harp (USGS), and Griggs (UCSC)

Landslides

1990 Seismic Hazards Mapping Act

State Requirement:

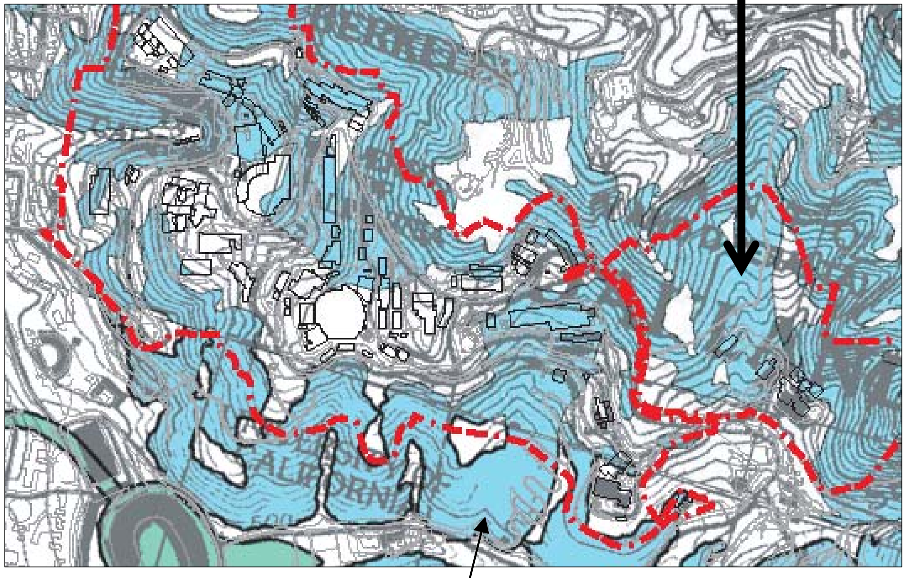
Recommendations for appropriate mitigation be developed, where needed.

Implementation/Mitigation:

The State defines Zones of Required Investigations where there is a potential for seismic landslides to occur.

Within these Zones; geologic investigations must be conducted for new projects to check for hazards and recommend appropriate mitigation.

Example Case



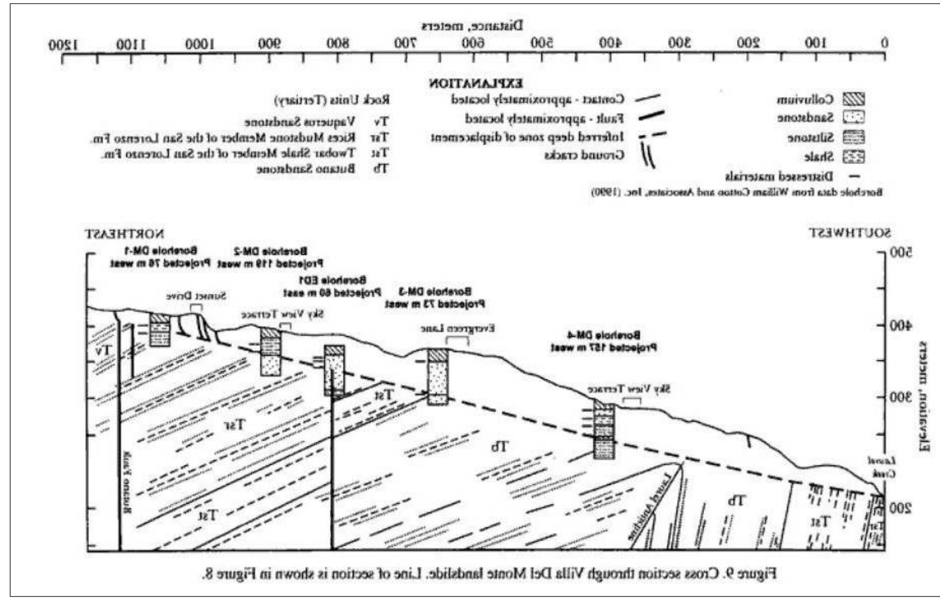
Zone of Required Investigation for Seismic Landslides (Blue)

Landslides

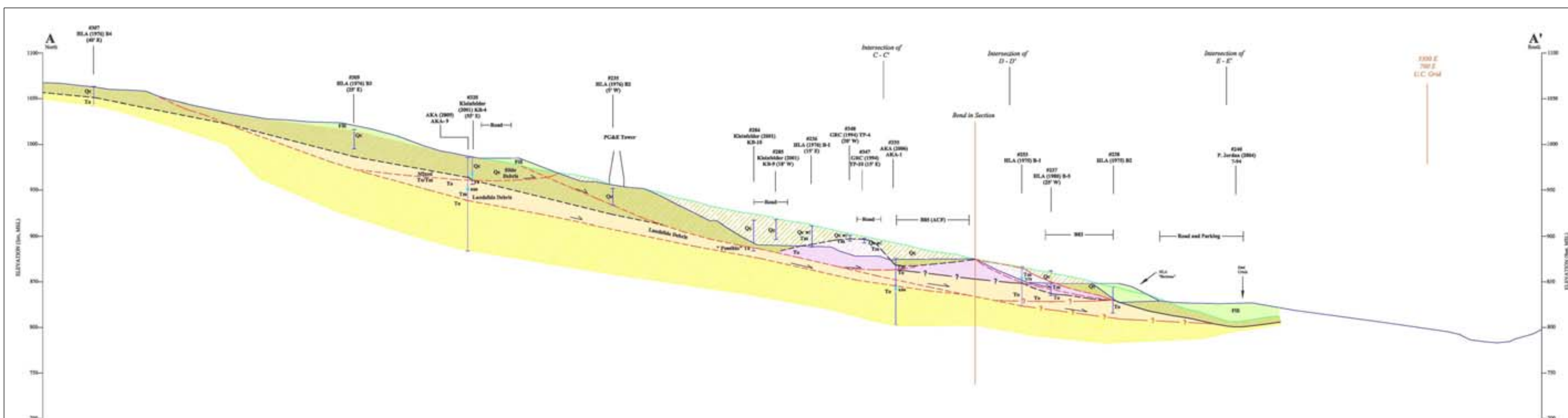
1990 Seismic Hazards Mapping Act

Analyze two ways:

1. Using engineering methods
2. Comparing to actual behavior under similar conditions



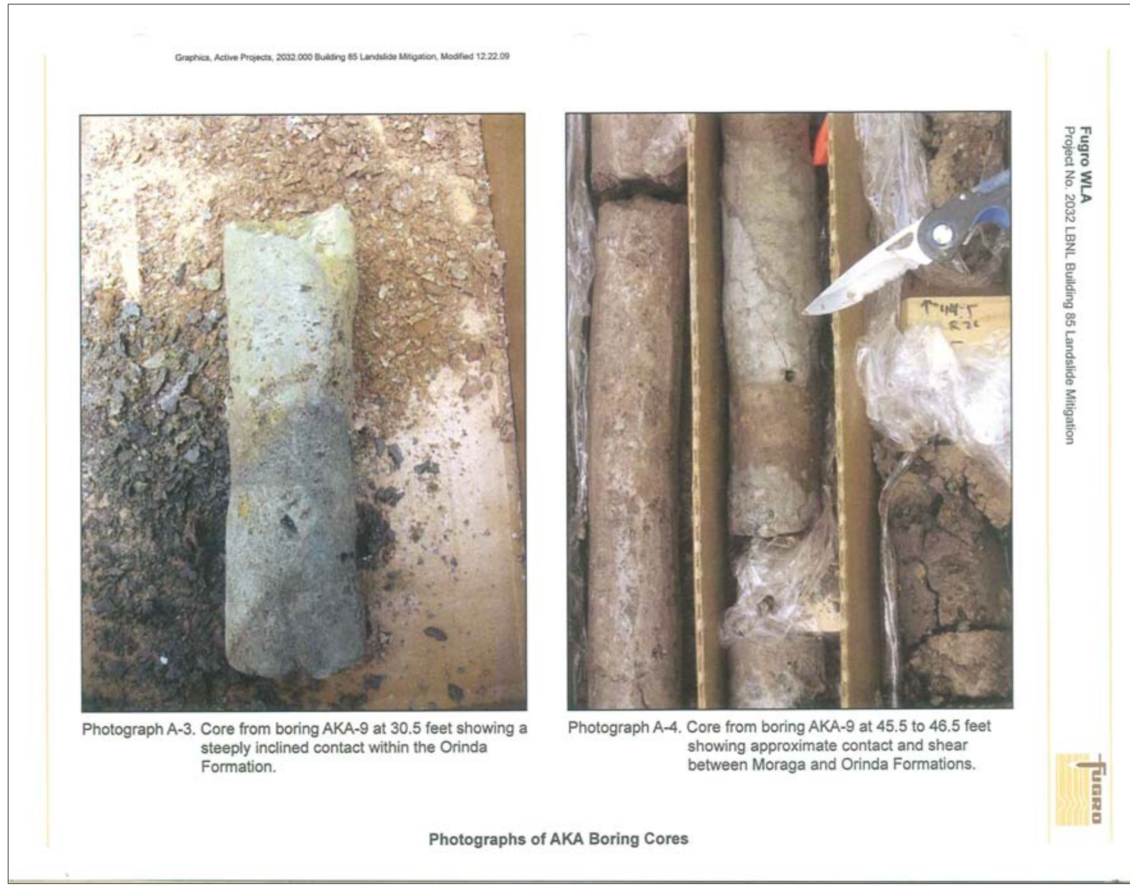
1989 Loma Prieta Landslide



Example Landslide at LBNL

Landslides

1990 Seismic Hazards Mapping Act



Graphics, Active Projects, 2032.000 Building 85 Landslide Mitigation, Modified 12.22.09

Photograph A-3. Core from boring AKA-9 at 30.5 feet showing a steeply inclined contact within the Orinda Formation.

Photograph A-4. Core from boring AKA-9 at 45.5 to 46.5 feet showing approximate contact and shear between Moraga and Orinda Formations.

Photographs of AKA Boring Cores

Fugro WLA
Project No. 2032 LBNL Building 85 Landslide Mitigation

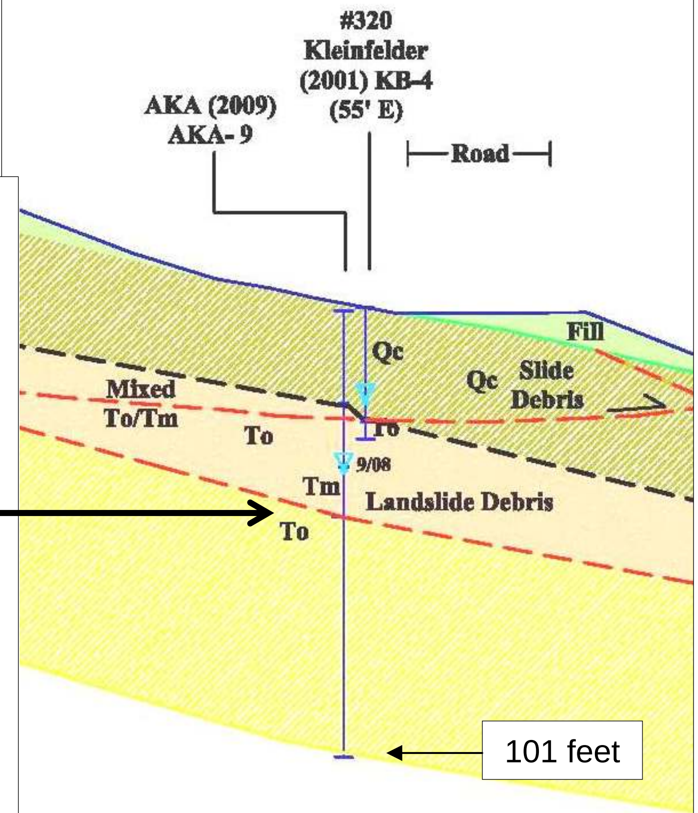
Borings to 100+ feet - Continuous Core

Landslides

1990 Seismic Hazards Mapping Act

Base of Landslide Deposits:

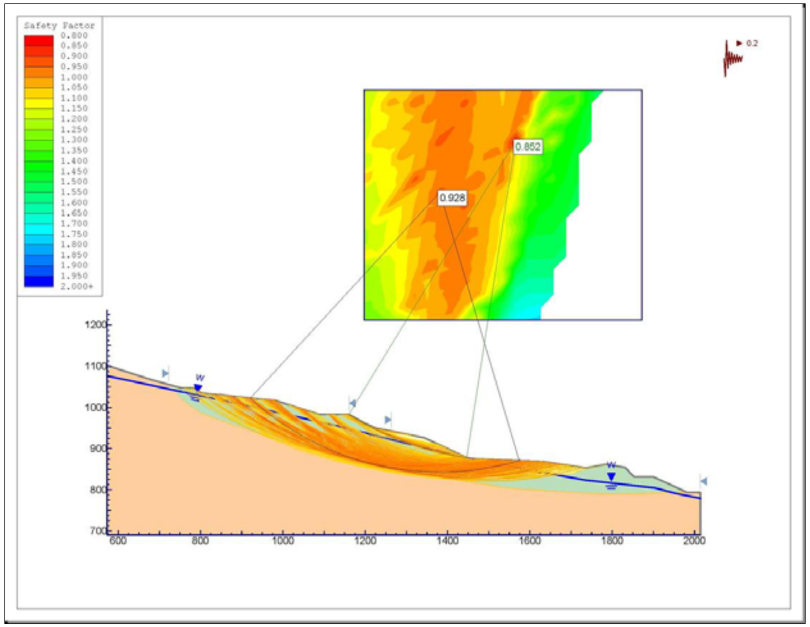
DESCRIPTION AND REMARKS	COLOR	CONSISTENCY	SOIL TYPE	DEPTH (ft)	SAMPLER TYPE	SAMPLER BLOW COUNTS	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	OTHER TESTS
(Continued from Previous Page)									
-displaced Tm (Qls)	Light Brown		CL/GC	43, 44					
-crystaline rock fragments and clay -45.5' - 46.5': basal shear zone, separates Tm from Tor, very distict zone of disruption bounded by reddish brown clay seams	Reddish Brown			45, 46					PP = 3.5 tsf
CLAYSTONE/SILTSTONE - moist, low plasticity, massive to finely bedded, contains gravel, Orinda Formation -47.5': 0.01' thick clay seam, 50 degree dip, minor Qls basal shear	Dark Reddish Brown and Dark Greenish Gray		BED ROCK	47, 48					
-49': 40 degree dipping shear, minor Qls basal shear				49					PP = 4.0 tsf
-50.2': clay seam, 0.1' thick, subvertical within siltstone	Yellow/Brown/Green/Red			50					
-51.3': 0.1' thick gravel lense with sharp boundaries marked by clay bedding -dry, sub-horizontal partings, calcite stingers and nodules present	Green Yellow/Blue/Green/Red			51, 52					PP = >4.5 tsf
-53.3': 40-50 degree clay seam, coarse sandstone above siltstone -53.5 - 54': coarsened by high concentration of calcite crystals, 20% fine sand, heavily mottled	Greenish Gray			53, 54, 55					
-harder, paler				56					



Landslides

1990 Seismic Hazards Mapping Act

Slope Stability Analyses:

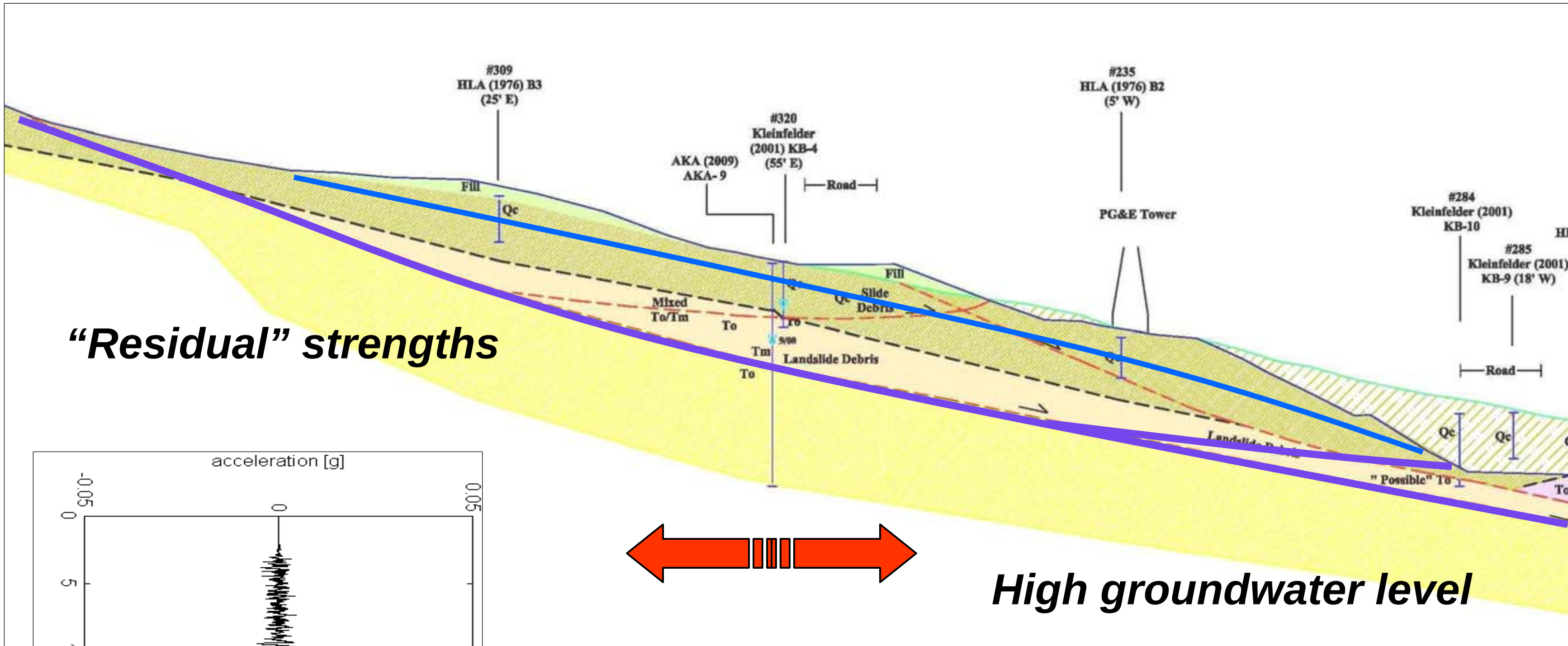


Key Parameters affecting Stability:

1. Strength of slide materials
   - weak is less stable - lab tests determine weakest (residual) strength
2. Groundwater level
   - high is less stable – high groundwater levels assumed in the analysis

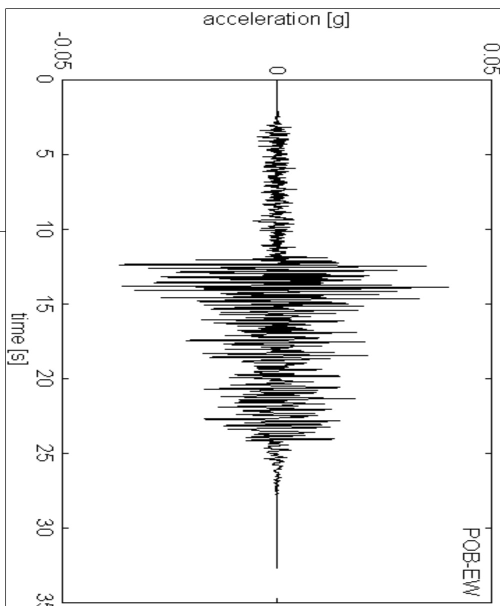
Landslides

1990 Seismic Hazards Mapping Act



"Residual" strengths

High groundwater level



475-year return period earthquake

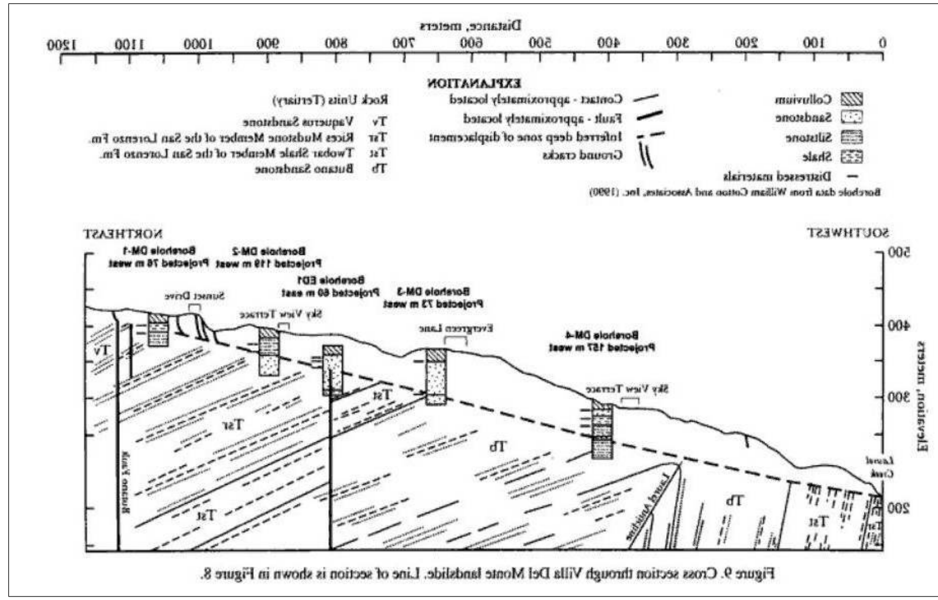
Calculated Seismic Displacement = 4 to 15 feet

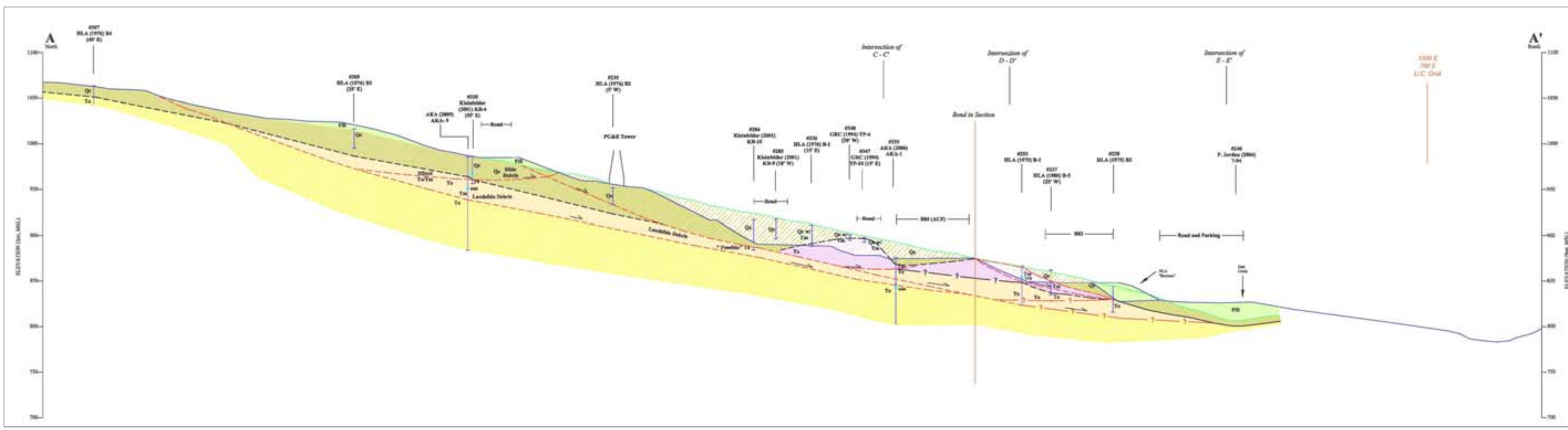
Landslides

1990 Seismic Hazards Mapping Act

How does this compare with observed performance?

1. Loma Prieta = about 3 feet
2. LBNL = 4 to 15 feet





Both show limited and incremental downslope movement
Conclusion: these are not "runaway" landslides

Landslide Hazard Mitigation at LBNL

Large Slides:

Avoidance
(move to a different location)

Accommodate Movement
(Stiff structure away from margins)

Small Slides:

Excavate and replace
(engineered fill - grading)

Strengthen/Retain
(walls, below-grade structures)

Lower groundwater
(combined w/ other methods)

Category	Recommended Mitigation Method	Important Considerations
Initial Grading	Excavate to competent material and and replace with engineered fill.	Most commonly used method of large-scale landslide treatment during initial grading. Drainage galleries, benching, compaction and scarification provided by design. Requires sufficient stability to resist maximum allowable seismic "triggering" displacement.
Remedial Grading	Reconfigure the mass to a more stable configuration at a lower slope angle.	Grade to reduce the slope geometry: remove material from the head and add counterweight material and key trenches in the toe area. Usually done in conjunction with dewatering. Area must be accessible to equipment and a disposal site is required for excavated material.
Engineered Fill	Construct cut and fill benches to provide level building sites, roads and utilities.	Overexcavate all transition pads or avoid building over a cut-fill transition contact to reduce uneven seismic ground response.
De-watering and Drainage	Prevent "loading" of natural or engineered slopes.	Reduce water content by grading, draining or pumping water to surface ditches. French drains and dewatering wells need to be routed to a stable drain outlet.
Slope Reinforcement	Construct buttress fill and compacted earth or rock berm at the toe of landslides.	Support the toe of a slope with properly engineered fill that is keyed into competent material below potential slip circles or adverse bedding.
Internal Slope Strengthening	Install rock bolts and/or soil nails to bind material together.	Effectiveness depends upon the grain size and character of the material and anchoring. May be used with gunite to strengthen slope face.
External Retaining Structures	Build gravity and cantiliever structures.	Must have sufficient mass or angular resistance to overcome the overturning earth pressures
Internal Retaining Structures	Install pilings and/or cassions.	Piling must be founded well below the potential slide plane and close spaced or tied together with grade beams.
Avoidance	Require the use of setbacks and deflection barriers.	Avoid the runout path, install a flow deflection barrier, provide and maintain upslope debris basins and clean out colluvial hollows.
Containment	Cover slope face with wire netting, may be used in conjunction with grouting or shotcret to increase strength.	The common treatment for rock falls and topples is to install wire netting on the rock face and barriers at the slope base or remove loose material from the face of slope by mechanical means.

Table 5: Recommended Landslide Mitigation Techniques (Modified from Popescu, 2001).

Landslides

1990 Seismic Hazards Mapping Act

Conclusions:

1. Landslides exist at LBNL at specific sites. The largest landslides at LBNL are less than 100 feet thick; most landslides are much smaller and many have been repaired.
2. Landslides at LBNL have limited displacement potential. There are no “runaway” landslides at LBNL that would affect buildings or people offsite.
3. Onsite, landslide hazards are mitigated using accepted mitigation methods in accordance with State regulations and guidelines.
4. New construction at LBNL appropriately mitigates landslide risks.

Geologic Hazard Mitigation
(Why It's Safe to Build at LBNL)

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