Basin and Range Province Seismic Hazards Summit III

Utah Geological Survey and Western States Seismic Policy Council

Day 3

Keynote

Technical Session 5 – Earthquake Engineering and Risk Mitigation: *Moderator: Pete McDonough, Questar Gas Company*

Technical Session 6 – Emergency Management and Public Safety: *Moderator: Bob Carey, Utah Division of Emergency Management*

Keynote

PREPARING FOR THE INEVITABLE

Major General Jefferson S. Burton, The Adjutant General
Utah National Guard, 12953 S. Minuteman Drive, Draper, Utah 84020
Jefferson.s.burton.mil@mail.mil

It is a point of fact that the Wasatch Front is seismically unstable. For those who concern themselves with disaster response and recovery, the occurrence of a major seismic event is not a matter of 'If,' but a matter of 'When.' We must plan for, prepare, and rehearse our responses to catastrophe, as our citizens expect us to be ready should the unthinkable occur.

Disasters are by their very nature chaotic, bringing with them potential loss of life, property loss, destruction of infrastructure, and uncertainty regarding the future. Our citizens will be looking for rapid response and instant solutions to pain and suffering. The 24-hour news cycle feeds this expectation.

Our response and recovery will require a whole of government and private sector approach. Every possible resource at the local, state, regional, and national level will need to be brought to bear. Pre-scripted agreements for support and detailed written plans are essential in this process. Our ability to communicate with the public will be paramount in restoring order, establishing public trust, and long-term recovery.

Ultimately, our efforts are aimed at providing rapid relief, restoring hope, and ensuring long-term recovery.

The following is a PDF version of the author's PowerPoint presentation.

Utah Air and Army National Guard

Major General Jefferson S. Burton, The Adjutant General

The men and women of the Utah National Guard stand ready to provide rapid relief, restore hope, and ensure long-term recovery.

State Mission

Respond to ‘all-hazard’ emergencies or disaster events within Utah or other states and territories, as directed by the governor.

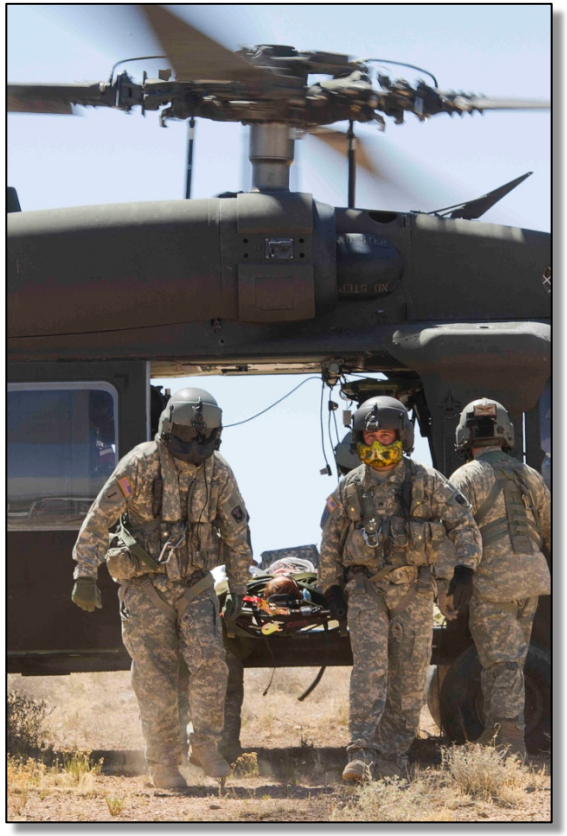
Flood Support

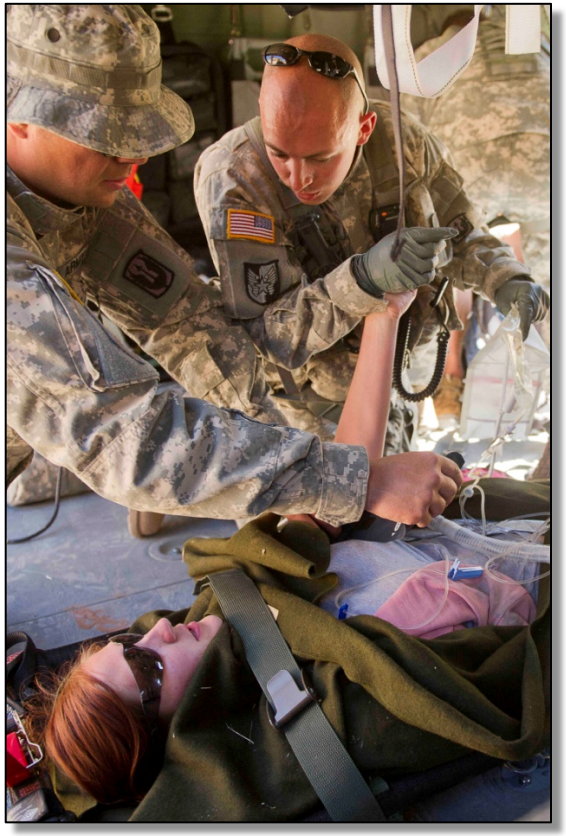
Rebuilding Roads in Colorado

Fixing Levee Breach in Weber County

Search and Rescue

Rescued several rafters in Emery County





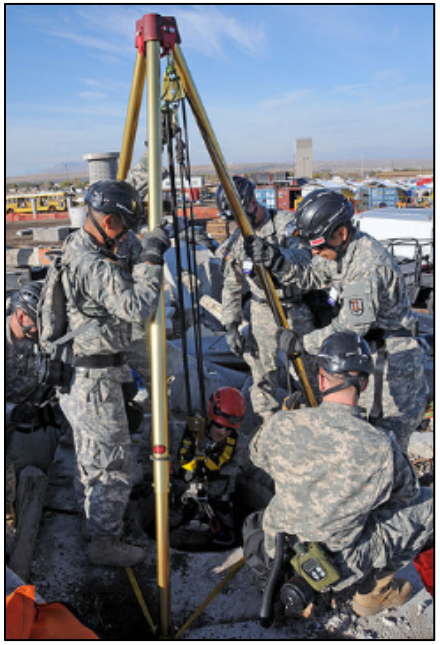
Wild Fire Support

Quail Fire, Utah County

Disaster Relief
Windstorm, Davis County

Civil Support
Hazmat, Layton

Earthquake Support
Trained and Ready



Questions?

Technical Session 5 – Earthquake Engineering and Risk Mitigation

Moderator: Pete McDonough, Questar Gas Company

Current Strategies for Mitigating Surface Faulting in the Basin and Range Province: *William Lund, Utah Geological Survey*

Engineering Mitigation of Surface-Fault Rupture: *Jonathan Bray, University of California, Berkeley*

Geologic Data Needs for Engineering Mitigation of Liquefaction Hazards: *Ross Boulanger, University of California, Davis* (PowerPoint only)

Reviewing Fault Surface-Rupture and Earthquake-Hazard-Mitigation Reports for Regulatory Compliance: *Robert Larson, Los Angeles County Department of Public Works*

Seismic Vulnerabilities of Natural Gas Systems: *Peter McDonough, Questar Corporation*

Protection of Pipelines from Permanent Ground Deformation Using EPS Geofoam: *Steve Bartlett, University of Utah*

CURRENT STRATEGIES FOR MITIGATING SURFACE FAULTING IN THE BASIN AND RANGE PROVINCE

William R. Lund
Geologic Hazards Program Senior Scientist
Utah Geological Survey, 88 East Fiddler Canyon Road, Suite C, Cedar City, Utah 84721
billlund@utah.gov

WHAT IS SURFACE FAULTING, WHY IS IT A HAZARD, AND WHAT IS AT RISK?

Surface faulting occurs when movement on a fault at depth breaks through to and ruptures the ground surface. In the Basin and Range Province (BRP), surface faulting occurs suddenly in earthquakes typically ≥**M**6.5. Surface faulting in the BRP chiefly occurs on normal faults (the most prevalent style of faulting in the BRP), but in some parts of the province, rupture on strike-slip and reverse faults is possible. Surface faulting may extend for tens of miles, and displacements can range from a few inches (e.g., 1934 **M**6.6 Hansel Valley, Utah earthquake; Walter, 1934) to several feet or more (e.g., 1915 estimated **M**7.75 Pleasant Valley, Nevada; 1932 **M**7.3 Cedar Mountain, Nevada; 1954 **M**7.1 Dixie Valley – **M**6.8 Fairview Peak, Nevada earthquakes) (U.S. Geological Survey [USGS], 2015a). Structures and lifelines subjected to surface faulting may experience significant damage or collapse.

There have been 14 historical surface-faulting earthquakes in the BRP over the past ~160 years (period of record longer in some areas). However, there are more than 1000 Quaternary-active (<1.6 myr) faults in the BRP, and of those, more than 250 are latest Pleistocene active (<15 kyr) (USGS *Quaternary Fault and Fold Database of the United States*, accessed January 2015). Slip rates for BRP faults range from ~0.001 to ~2 mm/yr and recurrence intervals between surface-faulting earthquakes range from hundreds to tens of thousands of years or more (Lund, 2005; Black and others, 1993; USGS, 2015b). The zone of surface faulting can range from a few feet to hundreds of feet wide (e.g., Black and others, 1996; DuRoss and others, 2014), and the width of the deformation zone can be highly variable over short distances. The formation of grabens with numerous smaller faults both antithetic and synthetic to the main fault trace is a common feature along many normal faults.

Despite its reputation for wide-open spaces, the BRP is a surprisingly urban place with most residents (11 out of ~12 million total [92%]; see Wong, this volume) living in medium to large urban centers. Many BRP communities are preferentially located at the base of mountain ranges, because mountains provide a reliable source of water. However, such locations can also put large populations in close proximity to Quaternary-active faults. Basin and Range Province communities astride Quaternary-active faults include numerous cities along Utah's Wasatch Front (Salt Lake City, American Fork, Orem, Provo, Spanish Fork, Bountiful, Ogden, Brigham City, etc.); Reno, Carson City, and Las Vegas, Nevada; Albuquerque, New Mexico; El Paso, Texas; and Jackson, Wyoming. It is important to note; however, that surface faulting is a localized phenomenon that only affects structures and lifelines built on or across hazardous faults (including grabens associated with normal faults). Only a small fraction of the population/area subject to strong ground shaking (by far the most damaging and deadly earthquake effect) during an earthquake large enough for faulting to rupture the ground surface will also be exposed to surface faulting.

SURFACE-FAULTING-HAZARD MITIGATION IN THE BASIN AND RANGE PROVINCE

In the BRP, only California, Utah, and Nevada have laws or ordinances that regulate surface-fault hazard at the state, county, or municipal level for structures intended for human occupancy.

California

California adopted the Alquist-Priolo Earthquake Fault Zoning (AP) Act state-wide in 1972, in response to the 1971 San Fernando earthquake (Bryant, 2010). The AP Act prohibits the location of most structures for human occupancy across a Holocene-active fault (Holocene defined as the past 11,000 years). The AP Act presumes, unless proven otherwise, that the area within 50 feet of a Holocene-active fault is also underlain by equally active branches of the fault (California Geological Survey, 2013).

The California Geological Survey (CGS) delineates AP Earthquake Fault Zones, and issues maps of the zones to cities, counties, and state agencies (Bryant and Hart, 2007). The fault-zone maps are available to the public, and allow individuals to make informed decisions regarding surface-faulting hazard. The CGS has also published guidelines for conducting surface-faulting investigations (California Geological Survey, 2002). Municipalities and counties must adopt local ordinances and rules to implement the AP Act. Although local rules and regulations may vary somewhat, the AP Act universally requires (1) a geologic report addressing surface faulting for any project in an Earthquake Fault Zone, (2) that the reports be reviewed for adequacy, and (3) that the reports be submitted to the CGS for archiving.

Current issues regarding the AP Act include (1) the long time period (Holocene Epoch) over which surface-faulting hazard must be evaluated compared to other kinds of earthquake and natural hazards, (2) any amount of Holocene displacement on a fault is sufficient to preclude development, and (3) only one form of surface-fault mitigation (setback and avoidance) is permitted.

Utah

In Utah, geologic-hazard (including surface faulting) ordinances are adopted at the municipal or county level; there is no state-wide regulation of geologic hazards. Consequently, coverage in some hazardous areas is incomplete, and the quality and efficacy of ordinances are variable. The Utah Geological Survey (UGS) has published guidelines for evaluating surface-fault-rupture hazards (Christenson and others, 2003 – currently being revised). The UGS guidelines are adopted in some ordinances, but not in others. Most Utah ordinances define an "active" fault as one that has experienced surface faulting in the Holocene (variously defined as the past 10,000 or 11,000 years). Some ordinances further quantify an active fault as one that has evidence of >4 inches of displacement in Holocene time. Some "4-inch" rules require additional geologic data showing that future fault displacement will not exceed 4 inches, others do not. Additionally, some ordinances require engineering (performance based) mitigation for small displacement faults, others do not. Review of surface-faulting-hazard reports can range from good to nonexistent depending on the jurisdiction.

Most Utah geologic-hazard ordinances mitigate surface faulting by setting structures for human occupancy back from active faults. Some ordinances adopt the setback formulas developed by Salt Lake County (2002), and recommended in the current UGS surface-fault-rupture-hazard guidelines (Christenson, 2003).

Downthrown side setback: $S=U[2D+F\tan\theta]$

Upthrown side setback: $S=U(2D)$

Where

S = Fault setback distance in feet within which buildings are not permitted.

U = Criticality factor based on International Building Code (IBC; International Code Council, 2012) occupancy categories.

D = Expected maximum vertical fault displacement in feet per earthquake.

F = Maximum depth of footing or subgrade portion of the building in feet.

θ = Dip of fault in degrees.

The calculated setback distances are then compared with a table of minimum setback distances determined for each IBC occupancy class, and the greater of the two distances is selected; except for those ordinances that apply the "4-inch rule" to small displacement faults.

One exception to the above methods of mitigating surface faulting in Utah is the City of Draper, located astride the Holocene-active Salt Lake City segment of the Wasatch fault zone in southeastern Salt Lake Valley. While generally adhering to the setback from Holocene faults and the "4-inch" rules for small displacement faults when mitigating surface faulting within city limits, Draper has adopted a special "Review Protocol," which permits performance-based, engineering-design mitigation (termed super-engineered structures in the protocol) of surface displacements larger than 4 inches (Draper City, 2005). Super-engineered structures are only permitted for single-family dwellings under limited circumstances, within limited areas, and with the property owner's full knowledge and acceptance of the hazard. A notice is attached to the property title documenting

that the structure has been built across an active fault to alert potential future property owners of the hazard. Design displacements for super-engineered structures in Draper have been as great as 6 feet (David Dobbins, Draper City Manager, verbal communication, 2015).

Nevada

The Nevada Earthquake Safety Council (NESC) has adopted and the Nevada Bureau of Mines and Geology has published *Guidelines for Evaluating Potential Surface Fault Rupture/Land Subsidence Hazards in Nevada* (Price, 1998). The NESC guidelines define a Holocene-active fault as a fault that has moved in the past 10,000 years, and recommends a setback of 50 feet from such faults unless otherwise specified by other State, Federal, or local guidelines. The NESC guidelines state that when deemed necessary, setbacks from fissures (assumed to be the result of ground subsidence caused by groundwater mining) and late-Quaternary-active (≤130,000 years) and Quaternary-active (≤1,600,000 years) faults will be as recommended by a competent professional. The guidelines do not define what constitutes a "competent" professional.

Both the Northern and Southern Nevada Code Amendments to the 2012 IBC Code reference the NESC guidelines (Northern Nevada Chapter of the International Code Council, 2013; Southern Nevada Chapter of the International Code Council, 2013). The Southern Nevada Amendments specify a 50-foot setback from Holocene-active faults and a 5-foot setback from other Quaternary-active faults. The Northern Nevada Amendments only specify the 50-foot setback in the NESC guidelines. The IBC amendments are adopted (or not) by local jurisdictions, so surface-faulting mitigation in some hazardous areas is incomplete. However, all larger Nevada urban centers (Reno, Carson City, Las Vegas, and some other smaller communities) have adopted the amendments and do require surface-faulting mitigation. There is no provision in the NESC guidelines for review of surface-faulting-hazard reports, nor were review requirements identified in the Nevada municipal and county codes examined to prepare this summary.

Only fault setback mitigation is permitted by the NESC guidelines and the Northern and Southern Nevada Amendments to the IBC code. Performance-based, engineering-design mitigation is not allowed, although there is anecdotal evidence that engineering mitigation has occurred under some circumstances in some jurisdictions.

Remaining Basin and Range Province States

The remaining BRP states lack state laws or local-government ordinances requiring mitigation of surface-faulting hazard for structures intended for human occupancy. These states include some large urban centers astride Quaternary-active faults (Albuquerque and El Paso), and numerous small- and medium-sized communities. Some state statutes do address surface faulting in their agricultural and/or waste-disposal regulations, although they chiefly appear intended to prevent groundwater contamination. Regulations for solid waste landfills and large commercial pig farms are prominent in this regard.

SOME OBSERVATIONS AND QUESTIONS

Surface-faulting ordinances commonly define an "active" and therefore presumably "hazardous" fault as one having experienced at least one surface-faulting earthquake during the Holocene; the Holocene usually defined as the past 10,000 or 11,000 years. This is an exceptionally long recurrence interval over which to mitigate a hazard, and far exceeds the recurrence intervals over which other kinds of earthquake and natural hazards are typically mitigated (Shlemon, 2010, this volume). By way of historical example, the Bronze Age, which began ~3300 BCE (~5.4 ka) is taken by some as the beginning of "organized" civilization, and the point in history when humans began constructing structures large, complex, and expensive enough for us to care whether they were destroyed by an earthquake or other natural hazard. Mitigating surface faulting to a Holocene standard then is mitigating to approximately 2 times civilization. What other natural hazard, including strong earthquake ground shaking, which is by far the most damaging and deadly earthquake hazard, is mitigated over such a long time period? As others have pointed out (Shlemon, this volume), the beginning of the Holocene marks the arrival of Clovis culture people in the Americas following the last Ice Age. Mitigating surface faulting to a Holocene standard effectively means mitigating to the Stone Age.

The observations above regarding the length of the Holocene compared to the span of human history raise legitimate questions concerning surface-faulting mitigation:

(1) While recognizing that for certain critical and hazardous facilities, evaluating surface faulting over the Holocene or even a longer time period may be appropriate, is there a shorter time period more relevant to *most* human endeavors that could be adopted for mitigating surface faulting that is more in line with the recurrence intervals used to mitigate other kinds of earthquake and natural hazards? Whereas, the Holocene most-recent-event (MRE) criterion was and remains useful to identify potentially hazardous faults when little else is known about a fault, once paleoseismic data become available, perhaps other criteria using both MRE and recurrence data should be developed.

(2) Does "Holocene-active" always mean "hazardous"? Basin and Range Province faults have a wide range of recurrence intervals, some measured in tens of thousands of years or longer. A fault with a long recurrence interval that has only experienced a single Holocene surface-faulting earthquake (especially a late Holocene event) may in fact not be hazardous in a time frame relevant to *most* human activities, or may not be as hazardous as other long recurrence-interval faults that have not yet had a Holocene earthquake, but are approaching or are beyond their average recurrence interval. Evaluating whether a fault is hazardous (a danger to society) or not, requires more information about the fault's earthquake history than just the timing of its most recent surface-faulting earthquake. Consequently, defaulting to a Holocene surface-faulting-mitigation standard as is the general practice in the three BRP states that mitigate surface faulting may in some instances require setbacks from non-hazardous faults, and in other instances cause more hazardous faults lacking a Holocene earthquake to be ignored.

(3) Where sufficient paleoseismic data are available, should data-driven, engineering-design surface-faulting mitigation be permitted rather than defaulting to a Holocene-active fault setback standard? And if so, how much paleoearthquake timing and displacement data are sufficient to evaluate surface-faulting hazard? It is recognized that for many projects, site geology will not provide the necessary information to support data-based, engineering-design mitigation, nor will many project budgets and schedules support the lengthy, detailed investigations required to acquire those data. For these reasons, the most commonly applied method of surface-faulting mitigation in the BRP will likely remain setting back from Holocene-active faults. However, where the data make it possible, should other performance-based, engineering-design mitigation options be available?

A final observation: geologic mapping and fault trenching investigations are key to surface-faulting mitigation in the BRP. It is not possible to mitigate a hazard that has not been identified, accurately located, and characterized. For most planning and hazard zoning purposes, a geologic map scale of 1:24,000 (1″ = 2000′) that covers both bedrock and unconsolidated deposits in equal detail (no large areas of undifferentiated unconsolidated Quaternary deposits) is sufficient. Mapping should focus on urban areas, surface faulting is not an important consideration where nothing of significance is at risk. Mapping using standard USGS 7.5-minute quadrangles is good, particularly if multi-hazard map folios are planned, but in some at-risk urban areas, including those with older quadrangle mapping, fault zone strip maps can be completed more quickly to directly address the hazard. The vast majority of Quaternary-active faults in the BRP have little or no available paleoseismic information, and therefore represent an unknown level of earthquake hazard. It is critical that unstudied or under-studied Quaternary faults in urban areas be investigated in research-level trenches so the earthquake timing and displacement data needed to evaluate their hazard can be obtained.

SUMMARY

- Large urban centers in the BRP are preferentially located at the foot of mountain ranges, which often places them in direct proximity to Quaternary-active faults creating a potential surface-faulting hazard.

- California has adopted a state-wide approach to mitigating surface faulting, and rules and regulations are rigorously enforced. Utah and Nevada adopt surface-faulting ordinances locally; as a result, coverage of hazardous areas is incomplete and ordinances vary in completeness and enforcement rigor. However, large urban centers in both states now generally require surface-faulting mitigation.

- Remaining BRP states have no statues either at the state or local level governing surface-fault-rupture mitigation for human-occupied structures. This leaves some large urban centers such as Albuquerque, New Mexico and El Paso, Texas, and other medium-size urban areas such as Jackson, Wyoming potentially vulnerable to surface faulting.

- Only some jurisdictions in Utah explicitly permit performance-based, engineering-mitigation of surface faulting, chiefly for small-displacement faults (4-inch rule), but at least one city permits engineering-design mitigation of faults exhibiting multiple feet of single-event displacement.

- Has the time arrived in the BRP to consider hazard recurrence intervals shorter than the Holocene for mitigating surface faulting, and should performance-based (data driven) engineering-design mitigation be generally permitted where sufficient information about a fault's earthquake history allows the surface-faulting hazard to be adequately quantified?

ACKNOWLEDGMENTS

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REFERENCES

Black, B.D., Hecker, S., Hylland, M.D., Christenson, G.E., and McDonald, G.N., 2003, Quaternary fault and fold database and map of Utah: Utah Geological Survey Map 193DM, scale 1:500,000.

Black, B.D., Lund, W.R., Schwartz, D.P., Gill, H.E., and Mayes, B.H., 1996, Paleoseismic investigation on the Salt Lake City segment of the Wasatch fault zone at the South Fork Dry Creek and Dry Gulch sites, Salt Lake County, Utah—Paleoseismology of Utah, Volume 7: Utah Geological Survey Special Study 92, 22 p.

Bryant, W.A., 2010, History of the Alquist-Priolo Earthquake Faulting Zone Act, California, USA: Environmental and Engineering Geoscience, v. XVI, no. 1, pp. 7–18.

Bryant, W.A., and Hart, E.W., 2007, Fault-rupture hazard zones in California—Alquist-Priolo Earthquake Fault Zoning Act with index to earthquake fault zone maps: California Geological Survey Special Publication 42 [Interim Revision 2007], 42 p.: Online, ftp://ftp.consrv.ca.gov/pub/dmg/pubs/sp/Sp42.pdf.

California Geological Survey, 2002, Guidelines for evaluating the hazard of surface fault rupture: California Geological Survey Note 49, 4 p.: Online, http://www.conservation.ca.gov/cgs/information/publications/cgs_notes/note_49/Documents/note_49.pdf.

California Geological Survey, 2013, The Alquist-Priolo Earthquake Zoning Act: Online, http://www.conservation.ca.gov/cgs/rghm/ap/Pages/main.aspx.

Christenson, G.E., Batatian, L.D., and Nelson, C.V, 2003, Guidelines for evaluating surface-fault-rupture hazards in Utah: Utah Geological Survey Miscellaneous Publication 03-6, 14 p.

Draper City, 2005, Review protocol for an administrative interpretation of Sections 9-10-070 and 9-19-080 of the Draper Municipal Code regarding the issuance of building permits for structures astride active faults in subdivisions approved prior to the adoption of the Draper City hazard ordinance: Draper City, 3 p.: Online, http://ut-drapercity.civicplus.com/documentcenter/view/989.

DuRoss, C.B., Hylland, M.D., McDonald, G.N., Crone, A.J., Personius, S.F., Gold, R.D., and Mahan, S.A., 2014, Holocene and latest Pleistocene paleoseismology of the Salt Lake City segment of the Wasatch fault zone, Utah, at the Penrose Drive trench site, *in* DuRoss, C.B. and Hylland, M.D., 2014, Evaluating surface faulting chronologies of graben-bounding faults in Salt Lake Valley, Utah—new paleoseismic data from the Salt Lake City segment of the Wasatch fault zone and the West Valley fault zone—Paleoseismology of Utah, Volume 24: Utah Geological Survey Special Study 149, 76 p., 14 appendices, CD.

International Code Council, 2012, International building code: Country Club Hills, Illinois, 694 p.

Lund, W.R., 2005, Consensus preferred recurrence-interval and vertical slip-rate estimates—review of Utah paleoseismic-trenching data by the Utah Quaternary Fault Parameters Working Group: Utah Geological Survey Bulletin 134, 109 p.

Northern Nevada Chapter of the International Code Council, 2013, 2012 Northern Nevada code amendments: Reno, Nevada, Northern Nevada Chapter of the International Code Council, 51 p.: Online, http://www.nnicc.org.

Price, J.G., 1998, Guidelines for evaluating potential surface fault rupture/land subsidence hazards in Nevada (Revision 1): Nevada Bureau of Mines and Geology, 9 p.: Online, http://www.nbmg.unr.edu/nesc/guidelines.htm.

Salt Lake County, 2002, Minimum standards for surface fault rupture hazard studies: Salt Lake County Planning and Development Services Division, Geologic Hazards Ordinance, Chapter 19.75, appendix A, 9 p.: Online, http://slco.org/pwpds/zoning/pdf/geologichazards/AppAfaultReportMinStds.pdf

Shlemon, R.J., 2010, A proposed mid-Holocene age definition for hazardous faults in California: Environmental and Engineering Geoscience, v. XVI, no. 1, p. 55–64.

Southern Nevada Chapter International Code Council, 2013, Southern Nevada amendments to the 2012 International Building Code: Las Vegas, Nevada, Southern Nevada Chapter International Code Council, 99 p.: Online, http://www.clarkcountynv.gov/Depts/development_services/plan_review/Building%20Codes/2012_IBC%20Amendments.pdf

U.S. Geological Survey, 2015, Nevada earthquake history: U.S. Geological Survey Earthquake Hazards Program: Online, http://earthquake.usgs.gov/earthquakes/states/nevada/history.php

U.S. Geological Survey, 2015, Quaternary fault and fold database of the United States: U.S. Geological Survey Earthquake Hazards Program: Online, http://earthquake.usgs.gov/hazards/qfaults/

Walter, H.G., 1934, Hansel Valley, Utah, earthquake: The Compass of Sigma Gamma Epsilon, v. 14, no. 4, p. 178–181.

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Current Strategies for Mitigating Surface Faulting in the Basin and Range Province

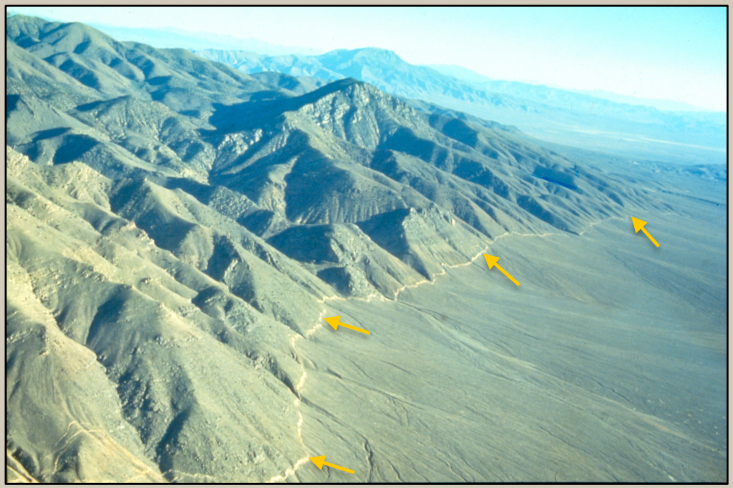
William R. Lund
Utah Geological Survey

What is Surface Faulting and Why is It a Hazard?

- Surface faulting occurs when movement on a fault at depth breaks through to and ruptures the ground surface.
- In the Basin and Range Province (BRP), surface faulting occurs suddenly in response to earthquakes ≥ M6.5.
- BRP surface faulting chiefly occurs on normal-slip faults, but in some parts of the Province rupture on strike-slip and reverse-slip faults is possible.

What is Surface Faulting and Why is It a Hazard?

- **Surface faulting may extend for tens of miles, and associated ground-surface displacements can range from inches to tens of feet.**



What is Surface Faulting and Why is It a Hazard?

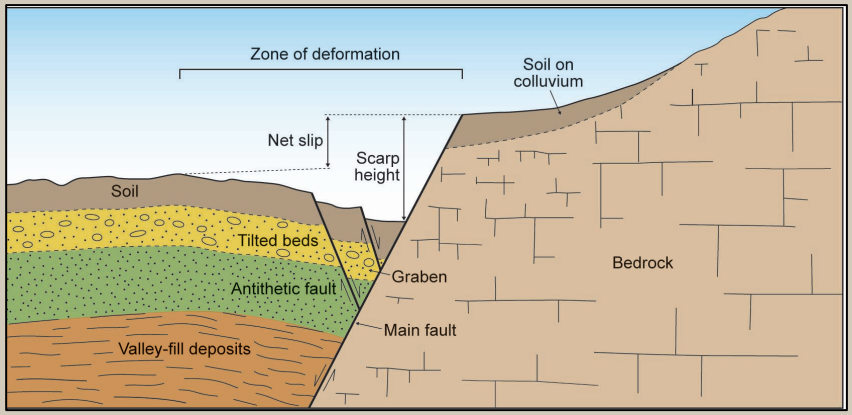
- **Structures and life lines subjected to surface-fault rupture may experience significant damage or collapse.**

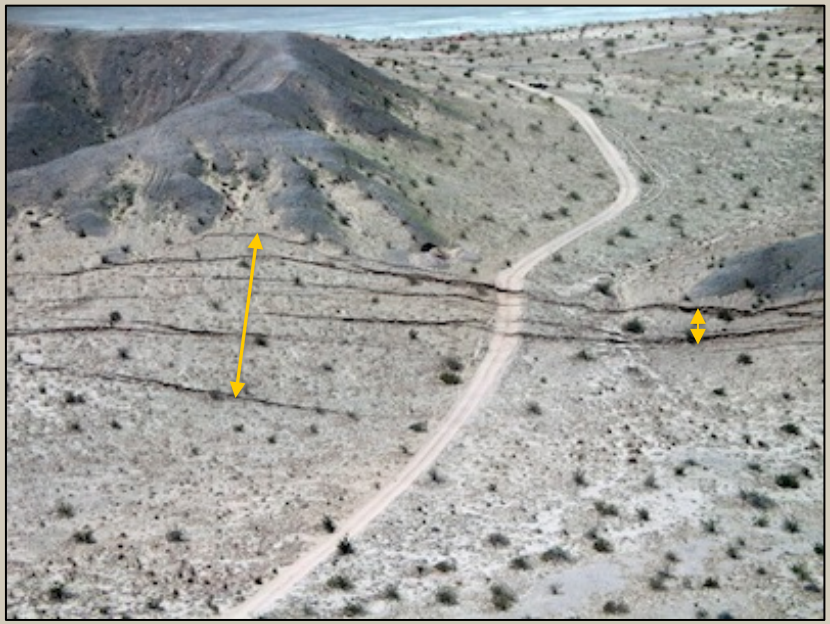
How Prevalent is BRP Surface Faulting and What is at Risk?

- ~14 historical surface-faulting earthquakes in the BRP; period of record ~160 years, longer in a some areas.
- More than 1000 Quaternary-active (<1.6 myr) faults in the BRP, of those more than 250 are latest Pleistocene active (<15 kyr).
- BRP fault slip rates range from ~0.001 to ~2 mm/yr, and recurrence intervals range from hundreds to tens of thousands of years.

How Prevalent is BRP Surface Faulting and What is at Risk?

- **Zone of surface faulting can range from a few feet to hundreds of feet wide, and be highly variable over short distances.**





How Prevalent is BRP Surface Faulting and What is at Risk?

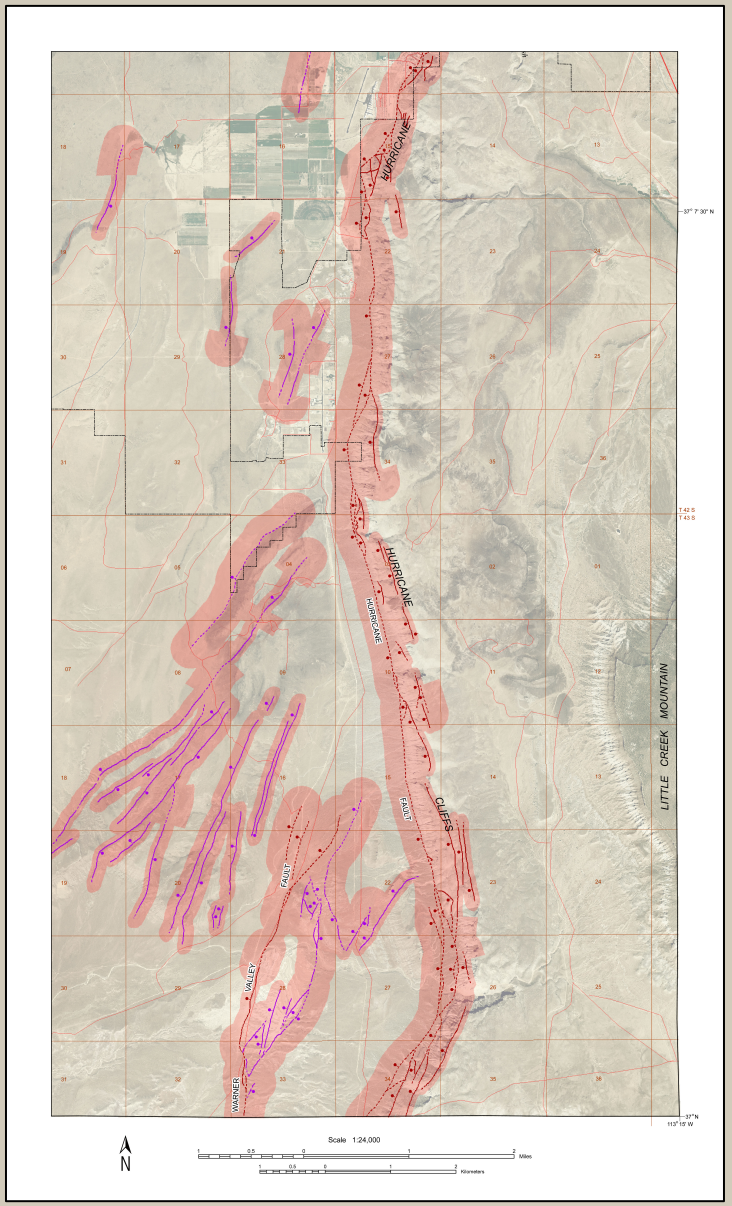
- The BRP is a surprisingly urban place; despite its reputation for wide open spaces, most BRP residents live in large urban centers.
- Many of the BRP's large urban areas are located at the foot of a mountain range, because mountains provide a source of water. Such locations can also put large populations in close proximity to Quaternary faults
- Major BRP cities astride Quaternary-active faults include:

Salt Lake City et al.	Las Vegas	El Paso
Reno - Carson City	Albuquerque	

Combined population ~ 6 million

How Prevalent is BRP Surface Faulting and What is at Risk?

Important caveat – surface faulting is a localized phenomena that only affects structures built directly on or across hazardous faults. Only a small fraction of the population/area subject to strong ground shaking during an earthquake large enough to rupture the ground surface will also be exposed to surface faulting.



Surface-Fault-Hazard Mitigation in the BRP

Currently surface faulting is mitigated by law or ordinance at the state or municipal/county level in three BRP states. In order of both precedence (first in time) and regulatory rigor they are:

- **California**
- **Utah**
- **Nevada**

California

Alquist-Priolo Earthquake Fault Zoning Act

- Passed in 1972 (effective in 1973) to mitigate the hazard of surface faulting to structures for human occupancy, adopted as a direct result of the 1971 San Fernando earthquake.
- Prohibits the location of most structures for human occupancy across the trace of a Holocene-active (past 11,000 years) fault.
- California State Mining and Geology Board formulates policies and criteria for administering the act and serves as an appeals board.
- California State Geologist delineates Earthquake Fault Zones and issues maps of the zones to cities, counties, state agencies.
- California Geological Survey publishes guidelines for conducting surface-faulting investigations

California

Alquist-Priolo Earthquake Fault Zoning Act

- Cities and Counties must adopt zoning laws, ordinances, and rules to implement the act.
- Presumes, unless proven otherwise, that the area within 50 feet of an active fault is underlain by active branches of the fault.
- Requires disclosure of Earthquake Fault Zones to the public.
- Requires a geologic report addressing surface faulting for any project affected by the Act.
- Requires that cities and counties review geologic reports for adequacy.
- Requires that the geologic reports be submitted to the State Geologist for archiving.

California

Alquist-Priolo Earthquake Fault Zoning Act

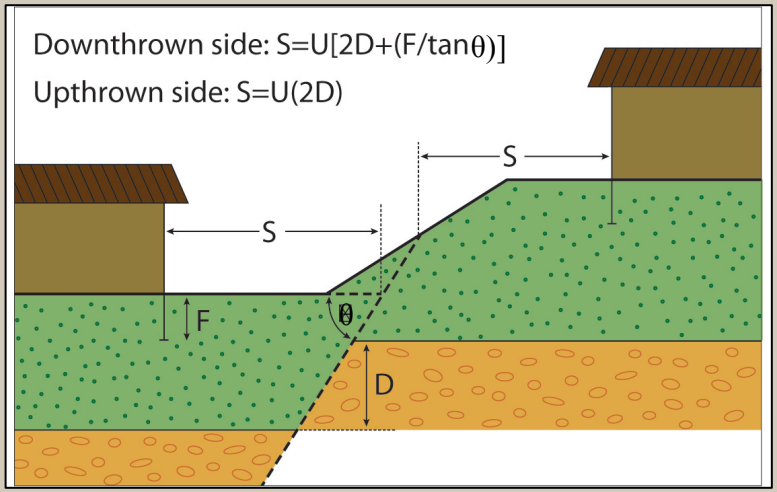
- **Things to like**
  - Applies state-wide, no patchwork of different regulations, or jurisdictions with no regulations at all.
  - Requires public disclosure – the public can make an informed decision about hazard.
  - Requires a geologic report that addresses the hazard.
  - Requires report review.
- **Issues**
  - Long time period (Holocene Epoch) over which surface faulting is evaluated compared to other earthquake and natural hazards.
  - Any Holocene displacement on a fault precludes development.
  - Prescriptive – only one way to mitigate, little professional judgment allowed.

Utah

- No state-wide coverage, geologic-hazard ordinances (including surface faulting) are adopted at the municipal or county level – coverage is incomplete and ordinance quality is variable.
- The Utah Geological Survey (UGS) has published guidelines for evaluating surface-fault-rupture hazard (Christenson and others, 2003; currently being revised); adopted in some ordinances but not in others.
- Most ordinances define an "active" fault as one experiencing surface faulting in the Holocene (generally defined as the past 10,000 or 11,000 years).
- Some ordinances further quantify an active fault as one that displays evidence of >4 inches of displacement in Holocene time.
- Some of the "4-inch rules" require additional geologic data showing that future displacement will not exceed 4 inches, others do not. Some ordinances require engineering (structural design) mitigation for small displacement faults, others do not.

Utah

Utah ordinances generally mitigate surface faulting by setting structures back from active faults, some ordinances adopt the setback formulas developed by Salt Lake County and recommended in the current UGS surface-fault-rupture-hazard guidelines.



where:

S = Fault setback distance in feet within which buildings are not per-mitted.

U = Criticality factor, based on IBC Occupancy Category.

D = Expected maximum fault displacement in feet per earthquake (maximum vertical displacement)

F = Maximum depth of footing or subgrade por-tion of the building in feet.

θ = Dip of the fault (degrees).

Utah

Although generally adhering to the "4-inch" rule, one Utah municipality under a special "Review Protocol" permits engineering-design mitigation ("super-engineered structures") of surface-faulting displacement in excess of 4 inches. Super-engineered structures are only permitted under limited circumstances within limited areas and with the owners full knowledge and acceptance of the hazard. Design displacements have been measured in feet not inches.

Utah

- **Things to like**
  - **Ordnances exist, and surface faulting is mitigated in some Utah jurisdictions.**
  - **UGS surface-faulting guidelines have received general acceptance, and are often used as a basis for conducting surface-faulting investigations**
- **Issues**
  - **No state-wide standard, surface-faulting mitigation is spotty, many areas with a significant hazard remain unregulated or poorly regulated.**
  - **"4-inch rule" may be applied with limited or no paleoseismic data. Slip during a single past earthquake is not sufficient data on which to evaluate future earthquake displacement.**
  - **The same is true for "super-engineered" structures, one displacement value is not sufficient for engineering-design mitigation.**
  - **Review of surface-faulting-hazard reports can range from very good to nonexistent depending on the jurisdiction.**

Nevada

- **The Nevada Earthquake Safety Council (NESC) has published *Guidelines for Evaluating Potential Surface Fault Rupture/Land Subsidence Hazards in Nevada*.**
  - **Defines a Holocene-active fault as a fault that has moved in the past 10,000 years.**
  - **Requires a minimum setback of 50 feet from Holocene-active faults unless otherwise specified by State, Federal, or local guidelines.**
  - **When necessary, set-back distances from fissures and Late Quaternary-active (≤ 130,000 yrs) and Quaternary-active (≤ 1,600,000 yrs) faults will be recommended by a competent professional.**

Nevada

- **Both the Northern and Southern Nevada Code Amendments to the 2012 IBC reference the NESC guidelines.**

- **Where required by 1803.5.11, *** investigation of hazards associated with surface displacement due to faulting or seismically induced lateral spreading or lateral flow shall be performed in accordance with *Guidelines for Evaluating Potential Surface Fault Rupture/Land Subsidence Hazards in Nevada*.**

- **The Southern Nevada Amendments to the 2012 IBC code specify a 50-foot setback from Holocene-active faults and a 5-foot setback from Quaternary-active faults (1808.10). The Northern Nevada IBC amendments rely on the 50-foot setback requirement in the NESC guidelines.**

Nevada

- **Things to like**
  - **The NESC surface-faulting evaluation guidelines are incorporated in the 2012 IBC Northern and Southern Nevada IBC code amendments.**
  - **Surface-faulting mitigation is occurring in most large Nevada urban centers with a surface-faulting hazard (Las Vegas, Reno, Carson City).**
- **Issues**
  - **Unclear how many other Nevada municipalities and counties with a surface-faulting hazard are mitigating the hazard.**
  - **No provisions for surface-faulting-hazard report review in the NESC guidelines, nor in any of the codes or ordinances examined.**
  - **Only fault setback mitigation permitted – engineering-design mitigation not allowed. Although there is antidotal evidence that some engineering-mitigation may in fact be occurring in some areas.**

Remaining BRP States

- **Lack ordinances requiring mitigation of surface faulting for structures intended for human occupancy. Includes some large urban centers with Quaternary-active faults – Albuquerque, El Paso, and other small and medium-size communities.**

- **Some state codes do address surface faulting in their agriculture and/or waste-disposal regulations, chiefly from the standpoint of preventing groundwater contamination (land fills and pig farms are prominent in this regard).**

- **Perhaps the recently concluded U.S. Geological Survey Workshop on *Evaluation of Hazardous Faults in the Intermountain West Region*, will bring a heightened awareness of the surface-faulting hazard in other BRP states.**

Summary

- Large urban centers in the BRP are preferentially located at the foot of mountain ranges, which often places them in direct proximity to Quaternary-active faults creating a potential surface-faulting hazard.

- California has adopted a state-wide approach to mitigating surface faulting, and rules and regulations there are rigorously enforced. Utah and Nevada adopt surface-faulting ordinances locally, and coverage is spotty and ordinances vary considerably in completeness and enforcement rigor. However, large urban centers in both states require surface-fault mitigation.

- Remaining BRP states have no statues either at the state or local levels governing surface-fault-rupture mitigation for human occupied structures. This leaves some large urban centers such as Albuquerque and El Paso and other medium-size urban areas such as Jackson, Wyoming vulnerable to surface faulting.

- Only Utah explicitly permits engineering-mitigation of surface faulting, chiefly for small displacement (≤4 inch) faults, but in at least one jurisdiction for faults exhibiting multiple feet of single-event displacement.

Observations/Questions

- **Surface-faulting ordinances commonly define an active fault as having experienced a Holocene surface-faulting earthquake (variously defined as within the past 10, 11, 11.5, or 11.7 kyr).**
  - **The Bronze Age (began ~3300 BC [5.4 ka]) is commonly taken as the point in human history when humans began creating structures large, complex, and expensive enough for us to care if they were destroyed by an earthquake. Mitigating surface faulting to a Holocene standard then is essentially mitigating to ~ 2 x civilization. I am unaware of any other seismic hazard, including those far more destructive and deadly than surface faulting, that are mitigated over such a long time period.**
  - **Is there a time period more relevant to <u>most</u> human endeavors that should be considered to bring surface-faulting mitigation in line with other earthquake-hazard mitigation?**
  - **Recognize that for certain critical and hazardous facilities, evaluating surface-faulting hazard over a period even longer than the Holocene may be warranted.**

Observations/Questions

- **Does "Holocene-active" always equate to "hazardous?"**
  - **BRP faults have a wide range of recurrence intervals, some measured in thousands to tens of thousands of years. A fault with a long recurrence interval that has only experienced a single Holocene surface-faulting earthquake (especially a late Holocene event) may in fact not be hazardous in a time frame relevant to most human activities, or may not be as hazardous as other long recurrence-interval faults that lack a Holocene surface-faulting earthquake, but are approaching or beyond their average recurrence interval.**
  - **Evaluating whether a fault represents a danger to society or not, requires more paleoseismic information than just the timing of its most recent surface-faulting earthquake.**
  - **Defaulting to a Holocene surface-faulting-mitigation standard as is common in the BRP may in some instances require more effort (expenditure of time and money) than the hazard justifies, and in other instances cause other more hazardous faults to be ignored.**

Observations/Questions

- **Where sufficient paleoseismic data are available, should decisions regarding surface-faulting mitigation in the BRP be data driven rather then defaulting to a Holocene-active setback standard?**
  - **How much paleoearthquake timing data are "sufficient" to make a meaningful evaluation of surface-faulting hazard in the BRP?**
  - **Similarly, how much paleoearthquake displacement data are "sufficient" to permit engineering-mitigation of surface faulting?**
  - **Recognize that not all sites can provide the information necessary to support data-based mitigation, nor can all project budgets and schedules support the level of detailed investigations required to acquire those data.**
  - **Expect that the most common method of surface-faulting mitigation in the BRP will remain setting back from Holocene-active faults, but should other mitigation options and faulting recurrence intervals be more widely available where the data permit?**

Observations/Questions

- **Geologic mapping and fault trenching investigations are key – can't mitigate a hazard that hasn't been identified, accurately located, and characterized.**
  - **Minimum mapping scale 1:24,000, cover bedrock and unconsolidated geologic units in equal detail – no big yellow Q blotches.**
  - **Focus chiefly on urban areas – where surface faulting places lives and property at risk.**
  - **7.5' quadrangle mapping is good (multi-purpose hazard evaluations), but in some at-risk urban centers, including urban areas with older quadrangle mapping, fault zone strip maps can be completed more quickly and directly addresses the hazard.**
  - **The vast majority of Quaternary-active faults in the BRP have little or no available paleoseismic information – again focus on urban areas for trenching investigations once those areas have been adequately mapped.**

Questions/Comments?

ENGINEERING MITIGATION OF SURFACE-FAULT RUPTURE

Jonathan D. Bray
Faculty Chair of Earthquake Engineering Excellence
Department of Civil & Environmental Engineering
University of California, Berkeley
Berkeley, California 94720-1710
jonbray@berkeley.edu

ABSTRACT

Designing facilities near active faults presents unique challenges that require an interdisciplinary approach. Sound engineering and earth science principles can be employed to address the hazards associated with surface-fault rupture. Robust procedures exist for evaluating the consequences of permanent ground movements. Whereas their use in designing systems to accommodate ground movements due to a variety of phenomena is widely accepted, their use in areas containing surface traces of active faults is often questioned, even when the anticipated ground movements are minimal. Active faults cannot always be avoided, nor should they be avoided, when their hazard is far less than other hazards, and the hazard can be effectively mitigated through the application of sound engineering concepts.

INTRODUCTION

Surface-fault rupture has severely damaged buildings and bridges during major earthquakes that produce significant ground deformations associated with differential movement along the ruptured fault (e.g., Bray 2001). While documentation of these cases of poor engineering performance is important, it is noteworthy that many other structures that were never designed for surface faulting did not fail when subjected to significant faulting. Unsatisfactory and satisfactory performances of buildings have been observed during these events.

Although avoidance of the trace of an active fault might be one's preference, it is not always a viable option. There are situations when lifelines or structures must cross active faults. There are cases when the traces of active faults are not discovered until after the building has been constructed. In other cases, the amount of potential fault movement is relatively small. Well engineered structures can be designed to accommodate the ground movements, so avoidance is not necessary. Rational design guidance is required for those cases when buildings need to be evaluated and designed to accommodate the hazards associated with surface-fault rupture.

EARTHQUAKE SURFACE FAULT RUPTURE

The phenomenon of earthquake surface-fault rupture is described in several publications, including Bonilla (1970), Sherard and others (1974), Cole and Lade (1984), Bray and others (1994a,b), Lazarte and others (1994), Bray (2001), Bray (2009), and Oettle and Bray (2013a,b). The principal hazards of earthquake surface-fault rupture are: (a) propagation of the distinct shear rupture plane to the ground surface, (b) differential movement or angular distortion of the ground surface, and (c) extensional or compressive horizontal strains at the ground surface. Ground deformations resulting from surface-fault rupturing have the potential to damage structures. However, similar to how engineers design structures to accommodate other forms of ground movements, such as expansive soils, mining subsidence, and differential settlement at soft soil sites, the hazards of surface-fault rupture can be accommodated for in design.

The factors that largely control the characteristics of surface faulting in the free-field are: (a) the type of fault movement (reverse, normal, or strike-slip), (b) the inclination of the fault plane, (c) the amount of displacement on the fault, (d) the depth and geometry of the earth materials overlying the bedrock fault, (e) the nature of the overlying earth materials, (f) the definition of the fault (i.e., well-established or more recently developed), and (g) the structure that can alter the ground deformations associated with surface faulting. Reverse faults tend to gradually decrease in dip near the ground surface (Bray and others 1994a). Normal faults tend to refract at the soil-bedrock contact and increase in dip as they approach the ground surface. This refrac-

tion and variation of the dip of the normal-fault plane may produce gravity grabens. Strike-slip faults tend to follow the almost vertical orientation of the underlying bedrock fault, although the rupture zone may spread or "flower" near the ground surface.

Differential movement across an underlying distinct bedrock fault dissipates as the shear rupture plane propagates through previously unfractured overlying soils. A deep, ductile earth mass can absorb a relatively minor amount of offset across an underlying bedrock fault. In these cases, a distinct surface rupture does not reach the ground surface; instead, the base movement is “spread out” over a wider zone. Thus, ductile earth materials may accommodate significant fault movement by warping without actually developing distinct shear surfaces. Ground warping and secondary ground ruptures are most significant over the hanging wall of dip-slip faults (i.e., over the upthrown block for reverse faults and over the downthrown block for normal faults). Once shear failure develops in the overlying warped earth mass, differential movement is localized primarily to thin, distinct failure planes within the earth. However, additional ground deformation will continue to occur adjacent to the fault primarily in the hanging wall of dip-slip faults and in ductile ground adjacent to a strike-slip fault.

The distance that a distinct bedrock rupture propagates up through overlying earth materials that were previously unfractured is primarily a function of the ductility of the overlying materials and the amount of relative displacement across the bedrock fault. Numerical simulations validated by the results of physical model experiments and the trends found in documented field studies indicate that at a specified amount of bedrock fault displacement, the height that the shear rupture will propagate up into the overlying soil increases as the failure strain of the soil decreases (i.e., as the soil response is more brittle; Bray and others, 1994b).

The angular distortion and lateral ground strain that would likely develop at the ground surface can be estimated through the use of calibrated numerical simulations. These calculations, with the application of engineering judgment, may be used to evaluate fault setback criteria when the ground deformation is significant, and to evaluate mitigation measures when the level of ground deformation can be made to be tolerable. For example, the ductility of the soil that overlies the bedrock fault has been found to be an important soil response characteristic. More ductile soils spread the distinct offset in the bedrock over a wider area, which limits differential ground movements and ground strain. Thus, geosynthetic reinforcement that increases the ductility of a compacted earth fill can be used to minimize the depth of over-excavation and the amount of earth fill required to mitigate the surficial hazards of earthquake fault rupture at a project site (Bray and others, 1993).

DESIGN CONCEPTS FOR THE SURFACE-FAULT-RUPTURE HAZARD

There are four categories of design concepts for addressing the potential hazards associated with earthquake surface-fault rupture: (a) land-use planning, (b) engineering geology, (c) geotechnical engineering, and (d) structural engineering. Each of these design concepts are discussed in this section of the paper.

Land-Use Planning Concepts

The most straightforward approach for addressing surface-fault-rupture hazard is avoidance through land-use planning. The California Alquist-Priolo Earthquake Fault Studies (A-P) Act of 1972 often serves as a model of this approach. It has been effective in restricting development atop active faults in the State of California. Other states have also adopted land-use planning regulations to address this hazard through avoidance.

The original intent of A-P Act; however, was to “provide policies and criteria to assist cities, counties, and state agencies in the exercise of their responsibility for the public safety in hazardous fault zones.” The original intent was to not locate a “structure within a delineated special studies zone if an undue hazard would be created …” Later in 1973, the California State Mining and Geology Board introduced the language of prohibiting structures with human occupancy “to be placed across the trace of an active fault.” There was a shift from “hazardous” fault to “active” fault, and a move from protecting the public from an “undue hazard” to not placing a structure “across the trace of an active fault.” Not all active faults are hazardous.

To provide some level of conservatism, the often misunderstood 50 feet (15 m) setback criterion was also added. It required that an area within 50 feet of a trace of an active fault “shall be presumed to be underlain by active branches of that fault unless proven otherwise ...” If an appropriate geologic investigation demonstrates that the ground adjacent to an active trace does not contain active branches of that fault trace, then a structure may be sited directly adjacent to the primary trace.

One of the primary deficiencies of the current version of the A-P Act is that it places all active faults in the same category. It

is not reasonable to treat the primary trace of the San Andreas fault, which could have meters of movement across it, in the same manner as an unnamed minor bending moment fault that may have moved once in the past 11,000 years a few centimeters. If land-use regulators allow engineers to mitigate major landslides, mining subsidence, and liquefaction-induced lateral spreads, they should also allow engineering mitigation of minor active faults. Also, it is sometimes impossible or too costly to avoid active faults.

Engineering Geology Concepts

The success of the every mitigation approach depends on a sound engineering interpretation of the regional and local geology. A comprehensive geologic study by a well-trained and highly experienced team of engineering geologists is critically important. The results of the geologic study provide the key fault parameters such as fault type; fault geometry; and the amount, sense, and distribution of potential ground movement associated with surface-fault rupture. Best estimates of each should be provided with upper and lower estimates at about the 16% and 84% probability levels to capture the significant uncertainty of this complex phenomenon. Surface faulting is no more complex than other earthquake hazards, such as ground shaking, liquefaction, and landsliding. These other hazards are often currently characterized through a probabilistic seismic hazard assessment that provides some assessment of the variability in the seismic demand parameter. Correspondingly, the surface-fault-rupture hazard should not be characterized only through a "worst" case deterministic assessment.

Ground deformations associated with surface faulting are not equally distributed on each side of the fault. Hence, the engineering geologist should work toward interpreting the geologic information to establish non-arbitrary setbacks based on specific site, fault, and soil characteristics. Although the profession requires continual enhancement of its understanding of surface faulting, sound judgment, coupled with reasonable interpretations of surficial geology and crack propagation theory, can be applied to develop earthquake-resistant designs without relying strictly on avoidance. Through mapping, trenching, and other tools, the engineering geologist can provide a reasonable description of the amount and type of potential fault displacement at the project site.

Geotechnical Engineering Concepts

The geotechnical engineer plays an integral role in developing effective design measures. Several interesting geotechnical concepts are discussed in the paper by Oettle and Bray (2013b). One geotechnical engineering approach is to use the inherent capability of soil to "locally absorb" the distinct offset across a bedrock fault. Differential movement across a distinct bedrock fault dissipates as the shear rupture plane rises through an overlying compacted earth fill, especially if it is reinforced with geosynthetics (Bray and others, 1993, 1994a, b). The relative displacement across the bedrock fault is spread across a wider zone of shearing in the reinforced earth fill. This spreading of the localized bedrock fault displacement over a wider zone at the ground surface reduces angular distortion and lateral ground strain at the foundation level. Hence, ductile compacted earth fills or reinforced earth fills may be used to mitigate earthquake-fault-rupture hazards.

An alternate approach is to construct a weak soil element, such as a bentonite slurry wall above a fault trace, to localize most of the differential fault movement across a narrow zone. By narrowing setback distances from the primary fault trace, more land would become available for development. The bedrock fault movement and the associated warping of the adjacent rock will eventually be expressed at the ground surface. The geotechnical engineer can help evaluate the amount and distribution of ground movement and either attempt to spread it out over a wider area or to localize it to a narrower zone.

Reinforced concrete mat foundations and interconnected spread footings, which should all have the same base elevation, can be constructed atop a double layer of smoothly laid-out polyethylene sheets sandwiched between layers of clean coarse sand to fine gravel to "decouple" anticipated ground deformation from the foundation elements. This defensive design measure will minimize the transfer of horizontal strains in the ground below the foundation to the structure. Trenches excavated to construct grade beams and underground utilities can be backfilled with loose soil or styrofoam to reduce lateral earth pressures that can develop on these elements.

Many of these geotechnical design measures have been used successfully in areas subject to ground deformations associated with mining subsidence. Several of these approaches are described in Kratzch (1983). Potential ground deformation beneath a structure from mining subsidence or expansive soils, for example, are routinely accommodated in foundation engineering. Most of these approaches can be employed to address the earthquake surface-fault-rupture hazard as well.

Structural Engineering Concepts

A building can be designed by an experienced structural engineer to undergo some limited amount of ground deformation without significant structural damage or collapse. The design of structures subjected to ground deformation resulting from other forms of ground deformation is generally applicable. Foundation elements should be heavily reinforced to improve ductility and their bases should be at the same elevation. The use of foundation elements that tie the structure into the ground should be avoided. Pile or pier foundations force the superstructure to undergo a large amount of differential ground displacement across the building's footprint. Likewise, a two-level foundation design would likely "lock" the building into the ground. The foundation elements should be designed to minimize the transfer of ground strain into the superstructure.

The maximum allowable angular distortion to limit architectural damage for many buildings, which includes a factor of safety of about 1.5, is 1/500. However, well-designed buildings can undergo significantly more angular distortion before structural damage occurs (i.e., approximately 1/150). Specially designed and built structures can tolerate even more ground distortion without posing a life safety risk to the building's occupants. The maximum allowable horizontal tensile ground strain below buildings is on the order of 0.3%. The combination of angular distortion and lateral strain of the ground, after considering that portion that will be transmitted into the building's foundation, should be considered in design.

There is likely no mitigation method (other than avoidance) that is more important than the use of a well-reinforced thickened mat foundation. There are countless examples of thick reinforced concrete foundations that undergo significant ground deformation without collapse. The use of waffle slabs or an integrated foundation of footings interconnected with substantial grade beams may also provide the foundation stiffness desired to bridge over gaps and span warped ground. Post-tensioning the floor slab will improve its ability to bridge over irregular ground deformation of limited extent.

In designing the structure, care should be also given to the selection of its structural system. A redundant, robust structural system can work with the building's foundation elements to reduce internal distortions and enable the structure to respond to ground deformations in primarily a rigid body mode. In those cases, where the structure and its foundation cannot be designed to withstand the anticipated ground deformation, isolation joints can be employed to control deformation within the structure. Flexible structures are also inherently more stable than stiff long structures that must accommodate differential ground movements across a wide zone. Lastly, if large ground movements are possible, then systems can be installed to keep system components from falling, such as catcher bents and ties.

CONCLUSIONS

In addressing surface-fault-rupture hazard, the potential patterns of ground deformation should be developed through the use of a comprehensive investigation and detailed mapping. Measured patterns of surface-fault-induced ground deformation from similar types of faulting from past events offer useful insights to complement site-specific investigations. Mitigation through the application of sound engineering design practices can be achieved in those cases when avoidance is not possible or practical. Engineers can design structures to accommodate fault-induced ground movements. Building strong, ductile structural foundation elements that can accommodate some level of ground deformation and isolating the superstructure from much of the underlying ground movement are effective design measures. Structures should not be tied into the ground with piles or piers. Other mitigation measures include establishing non-arbitrary setbacks based on fault geometry, fault displacement, and the overlying soil; constructing reinforced earth fills to partially absorb and spread out the underlying ground movements; using slip layers to decouple ground movements from foundation elements; and using compressible materials or voids to reduce ground-movement induced lateral earth pressures.

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REFERENCES

Bonilla, M.G., 1970, Surface faulting and related effects, *in* Weigel, R.L., editor, Earthquake Engineering: New Jersey, Prentice-Hall, p. 47-74.

Bray, J.D., Ashmawy, A., Mukhopadhyay, G., and Gath, E.M., 1993, Use of geosynthetics to mitigate earthquake fault rupture propagation through compacted fill: Proceedings, Geosynthetics '93 Conference, v. 1, p. 379-392.

Bray, J.D., Seed, R.B., Cluff, L.S., and Seed, H.B., 1994a, Earthquake fault rupture propagation through soil: Journal of Geotechnical Engineering, ASCE, v. 120, no. 3, p. 543-561.

Bray, J.D., Seed, R.B., and Seed, H.B., 1994b, Analysis of earthquake fault rupture propagation through cohesive soil: Journal of Geotechnical Engineering, ASCE, v. 120, no. 3, p. 562-580.

Bray, J.D., 2001, Developing mitigation measures for the hazards associated with earthquake surface fault rupture, *in* Konagai, K, editor, Seismic fault-induced failures—possible remedies for damage to urban facilities: Japan Society for the Promotion of Science, University of Tokyo, p. 55-79.

Bray, J.D., 2009, Earthquake surface fault rupture design considerations, Proceedings Sixth International Conference on Urban Earthquake Engineering: Tokyo Institute of Technology, Tokyo, Japan, March 3-4, p. 37-45.

Cole, D.A., Jr. and Lade, P.V., 1984, Influence zones in alluvium over dip-slip faults: Journal of Geotechnical Engineering, ASCE, v. 110, no. 5, p. 599-615.

Kratzsch, H., 1983, Mining subsidence engineering: Springer Verlag, Berlin, 543 p.

Lazarte, C.A, Bray, J.D., Johnson, A.M., and Lemmer, R.E., 1994, Surface breakage of the 1992 Landers earthquake and its effects on structures: Bulletin of the Seismological Society of America, v. 84, no. 3, p. 547-561.

Oettle, N., and Bray, J.D., 2013a, Fault rupture propagation through previously ruptured soil: Journal of Geotechnical Engineering, ASCE, v. 139, no. 10, p. 1637-1647.

Oettle, N., and Bray, J.D., 2013b, Geotechnical mitigation strategies for earthquake surface fault rupture: Journal of Geotechnical Engineering, ASCE, v. 139, no. 11, p. 1864-1874.

Sherard, J.L., Cluff, L.S., and Allen, C.R., 1974, Potentially active faults in dam foundations, Geotechnique, v. 24, p. 367-427.

The following is a PDF version of the author's PowerPoint presentation.

ENGINEERING MITIGATION OF SURFACE-FAULT RUPTURE

Jonathan D. Bray, Ph.D., P.E.

Faculty Chair in Earthquake Engineering Excellence

University of California, Berkeley

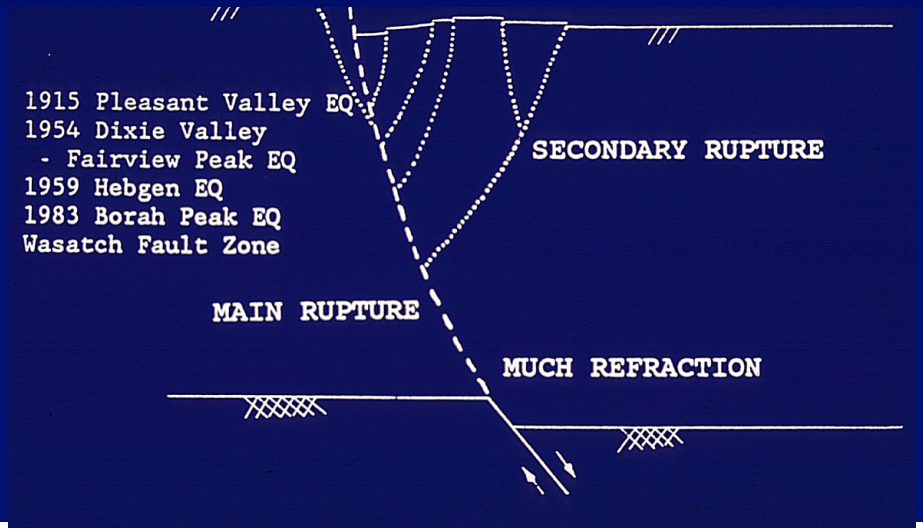
Sponsored in part by the National Science Foundation & GEER

Surface Fault Rupture Mitigation

1992 Landers Earthquake

1999 KOCAELI EQ

Footwall **NORMAL FAULT** Hanging wall



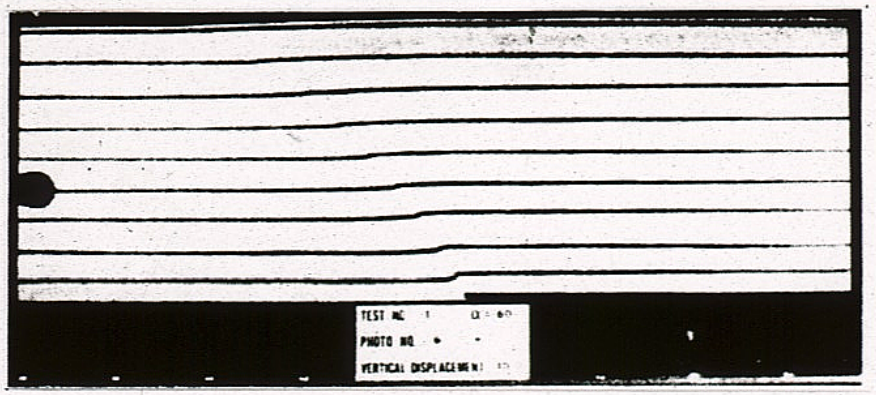
Broad Area of Building Damage on Hanging Wall of Reverse Fault

Not on footwall

1999 Chi-Chi EQ

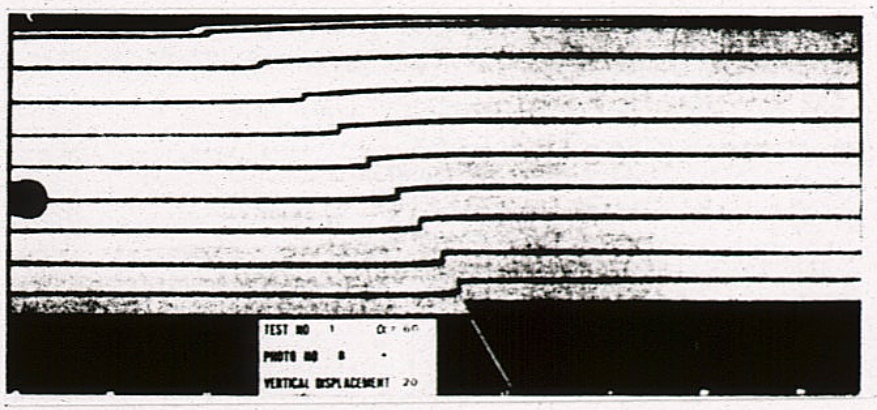
Soil Effects

1992 Landers EQ (Photo by E. Gath)



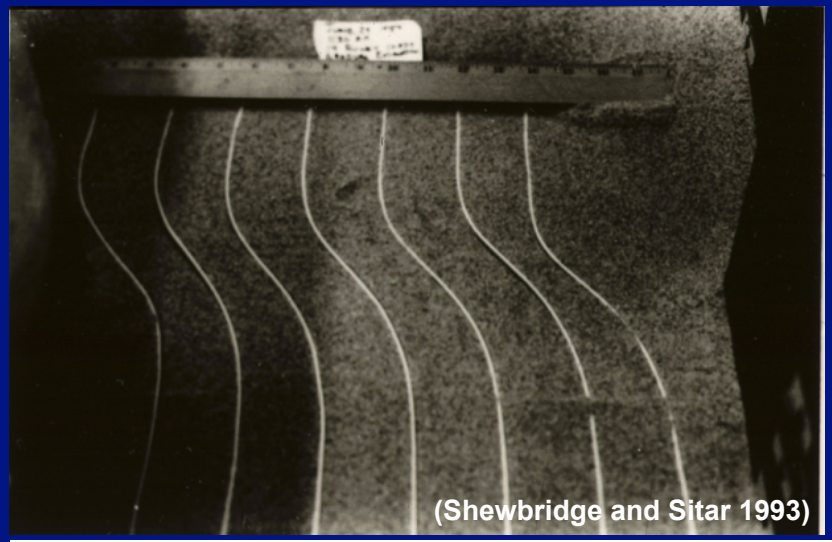
(B) Initiation Of Failure Surface At Bedrock Fault

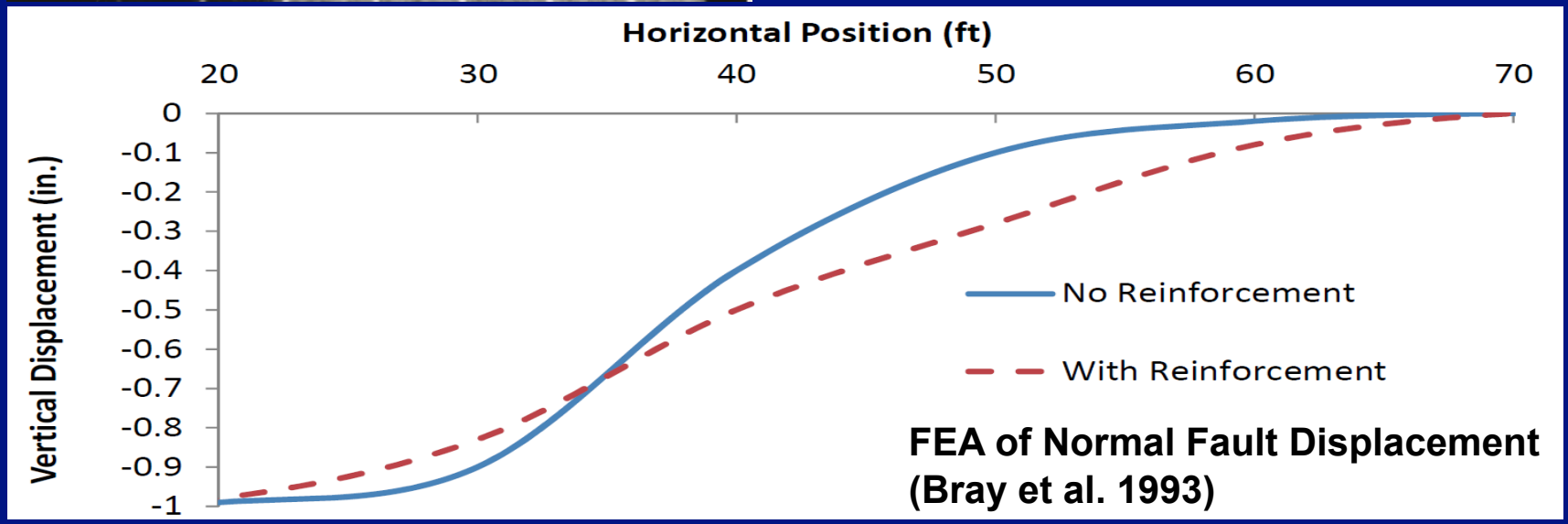
(Lade and Cole 1984)



(C) Fully Developed Failure Surface

REINFORCEMENT IMPROVES DUCTILITY

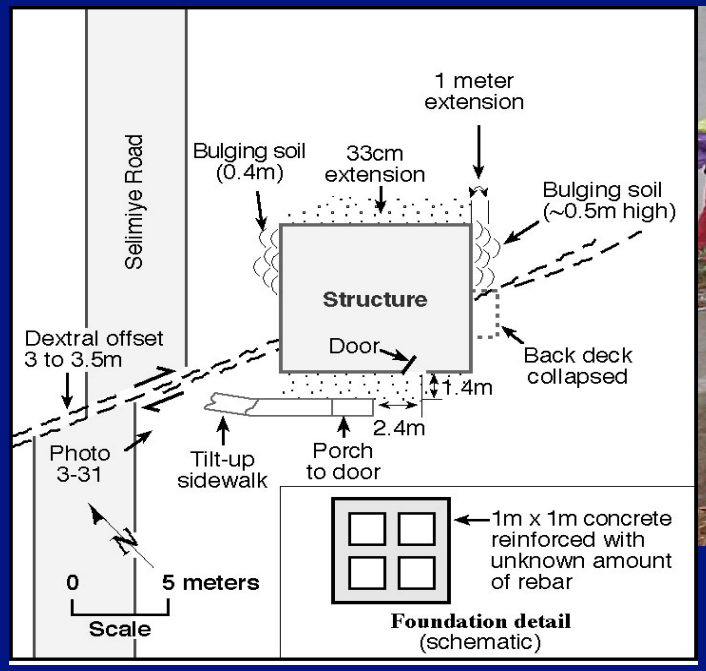


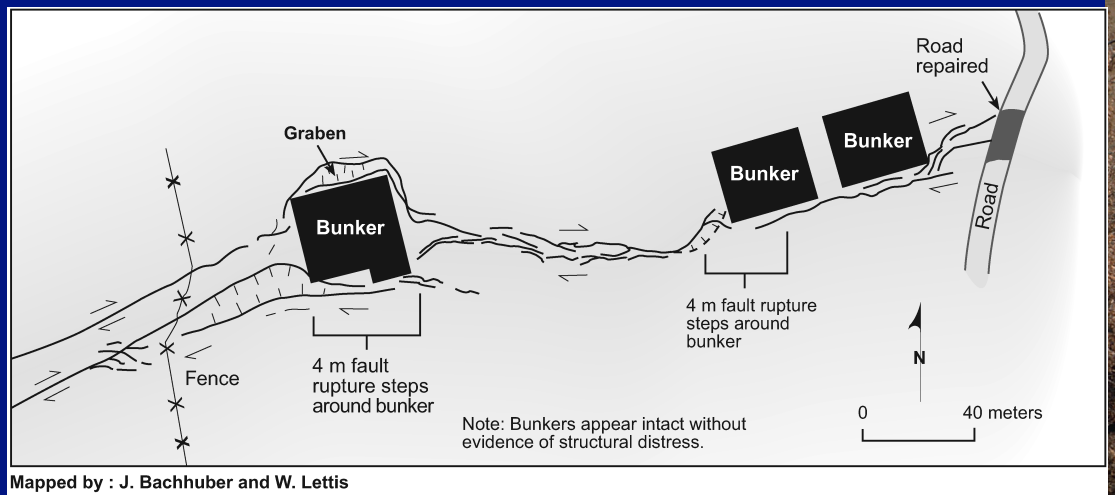


FEA of Normal Fault Displacement (Bray et al. 1993)

Systems (Tied to the Ground) Damaged by Faulting

Systems (Not Tied to Ground) Not Damaged by Faulting - Decoupling

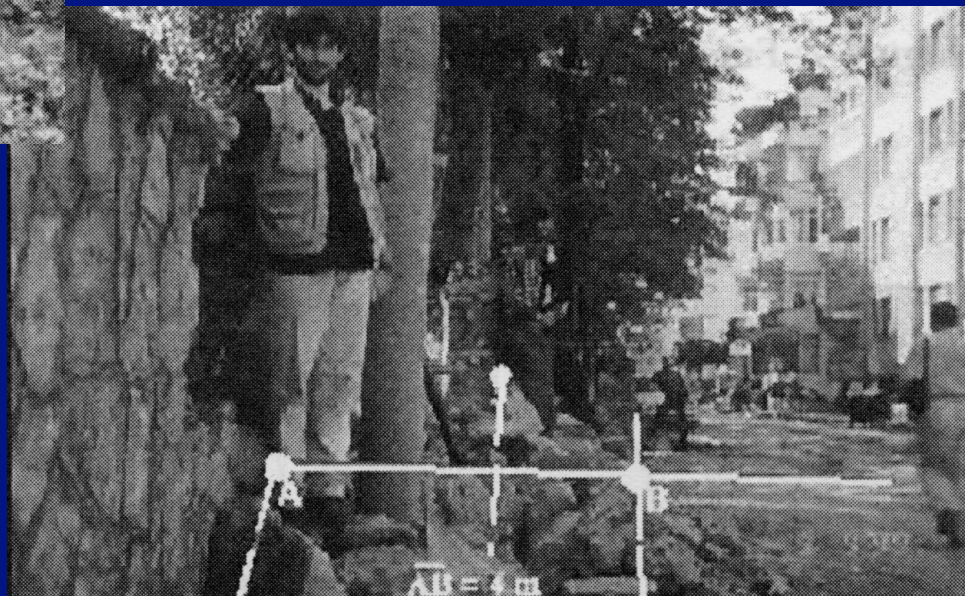




Mapped by : J. Bachhuber and W. Lettis

An Analogy

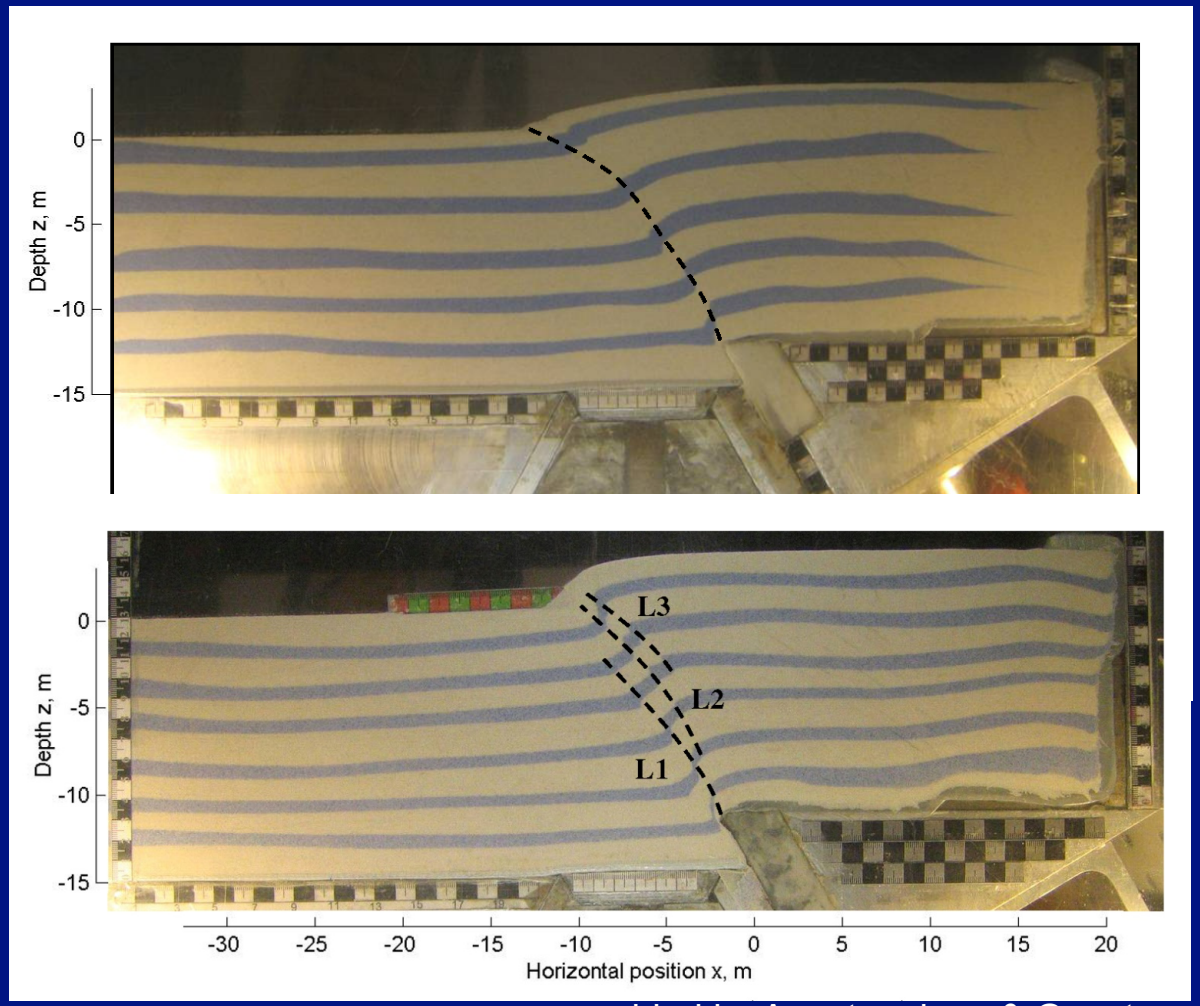
ROOTED TREE DAMAGED



POLE UNDAMAGED

Photographs from Prof. R. Ulusay, Turkey

MAT FOUNDATION DEFLECTS FAULT RUPTURE (Davies et al. 2007)

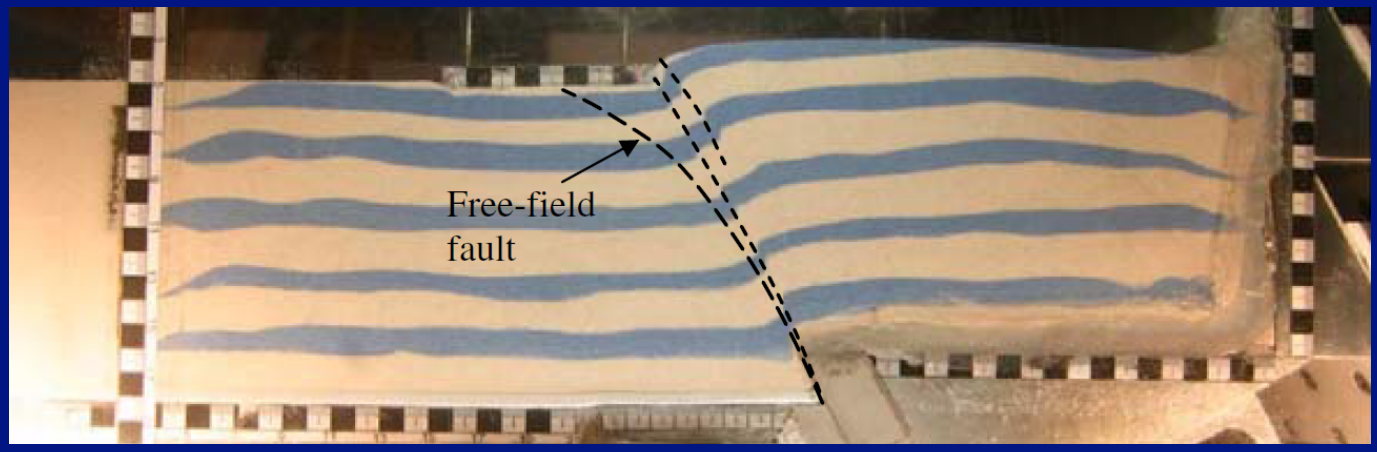


provided by Anastapolous & Gazetas

WEIGHT OF MAT FOUNDATION EFFECTS
(Davies et al. 2007)

Light Load:
q = 37 kPa

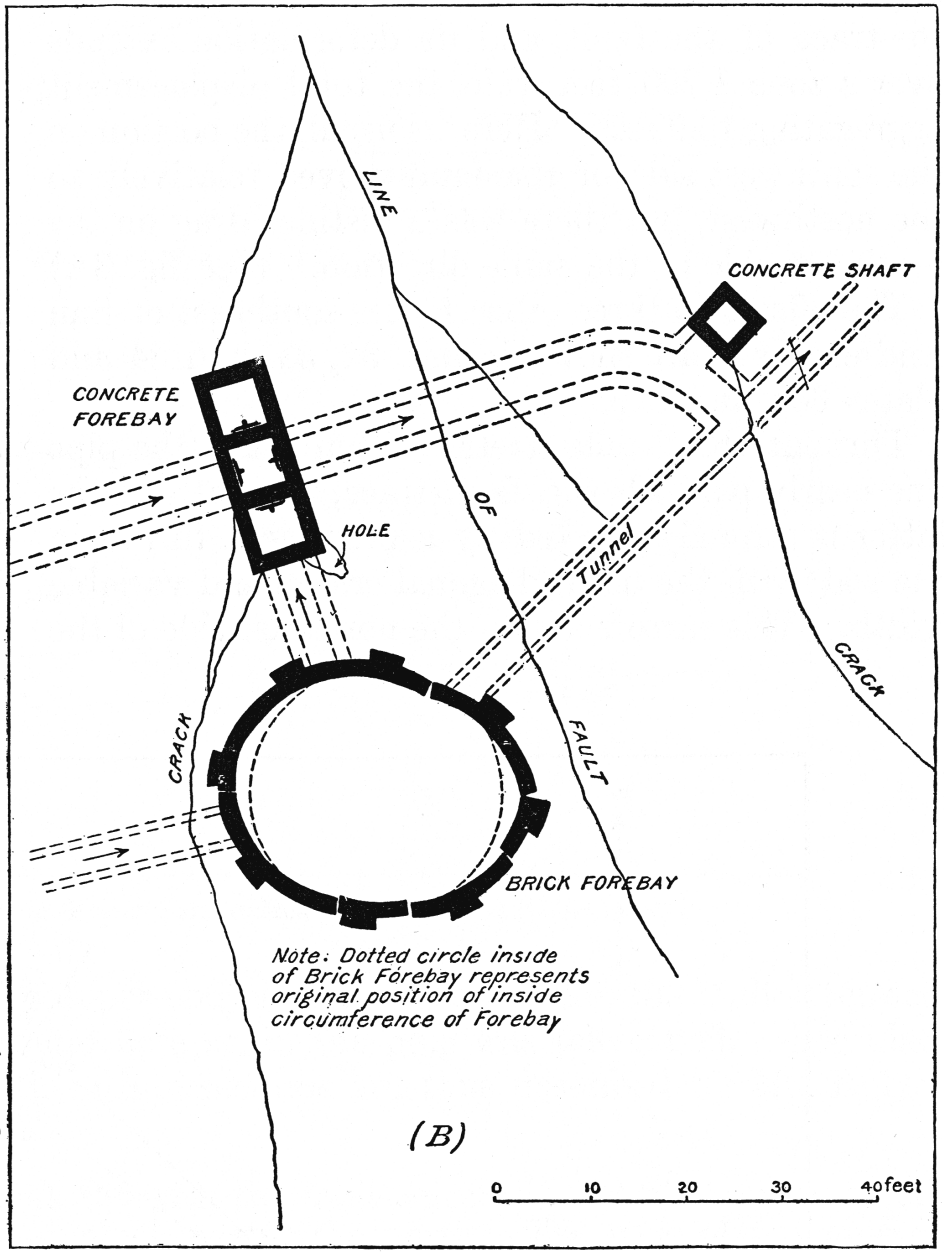
Heavy Load:
q = 91 kPa



provided by Anastapolous & Gazetas

FLEXIBILITY vs. RIGIDITY

Photographs from Dr. C. Roblee, Caltrans, 1999 Chi-Chi EQ



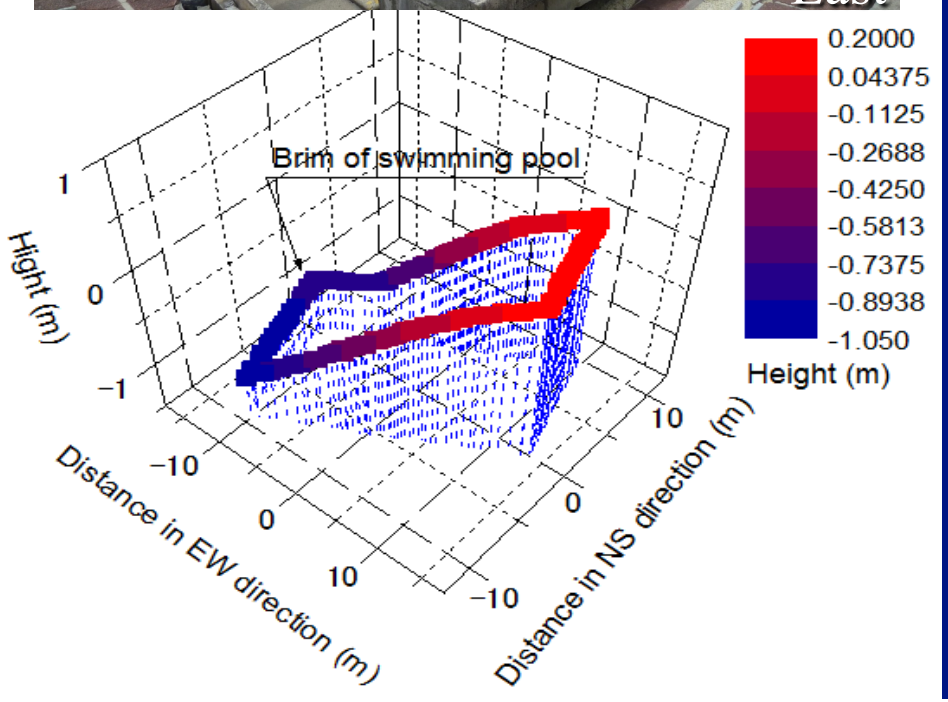
Response of Buried Systems

1906 San Francisco EQ

(Lawson 1908 & Schussler 1906)

"max. possible pressure is the passive earth pressure"

TABITO MIDDLE SCHOOL

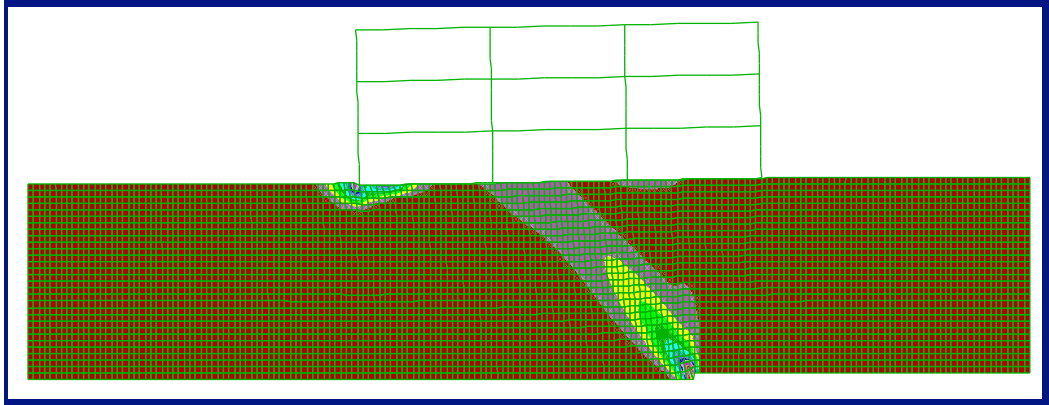


M_w 6.6 Hamadoori Aftershock of 4/11/11: Shionohira Fault Displacement

Laser survey of the brim of the pool (Konagai, Bray, Streig, & others)

1.25 m vertical displacement between ends of pool

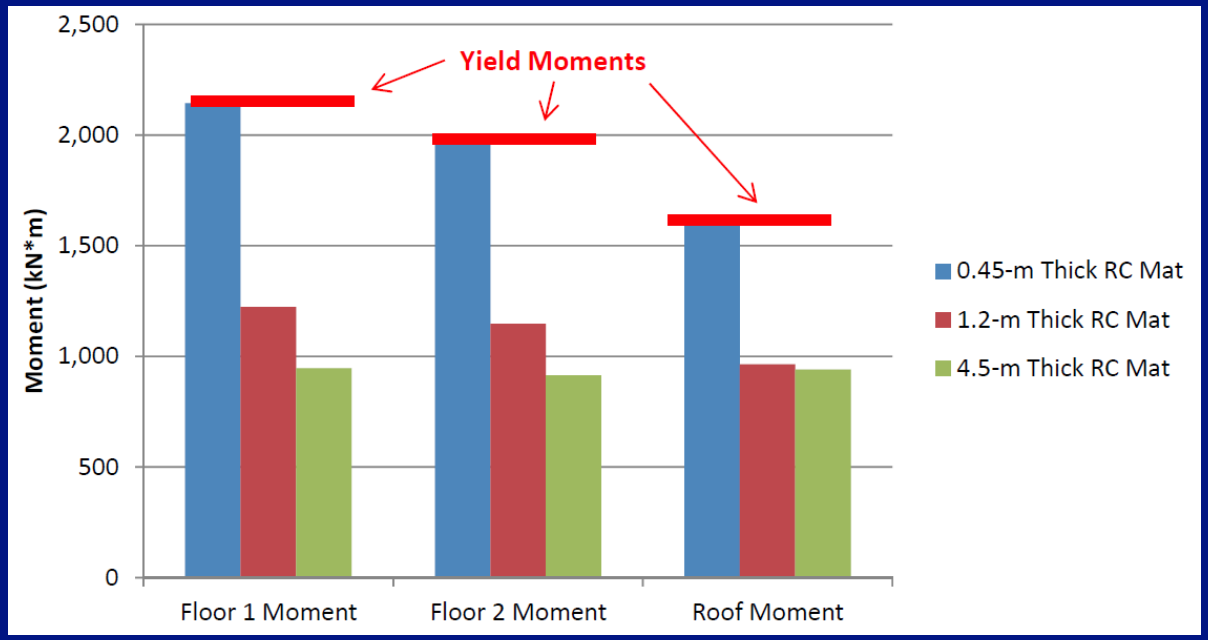
Fault-Structure Interaction Analyses



15 m deep sand deposit

70 cm reverse fault displ.

(Oettle & Bray 2013)

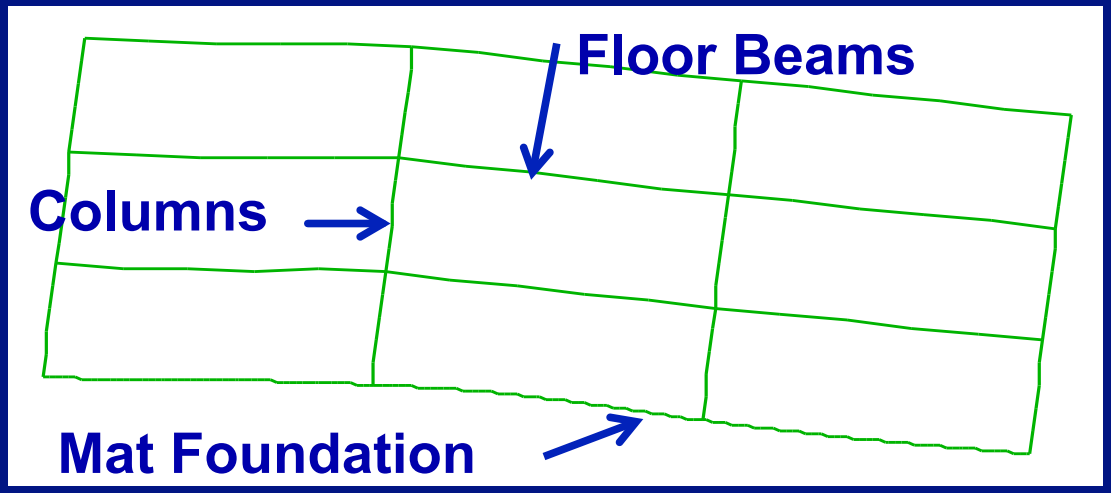


Thicker mat foundation significantly reduces building damage

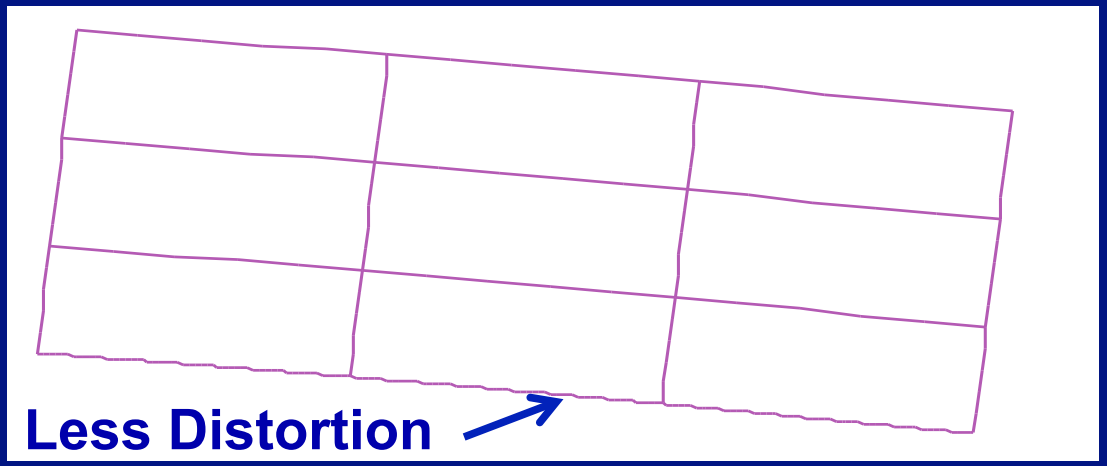
Mitigation with Thick Mat Foundation

Thicker mat foundation "shields" structure from ground deformation

Mat Thickness
= 1.5 ft



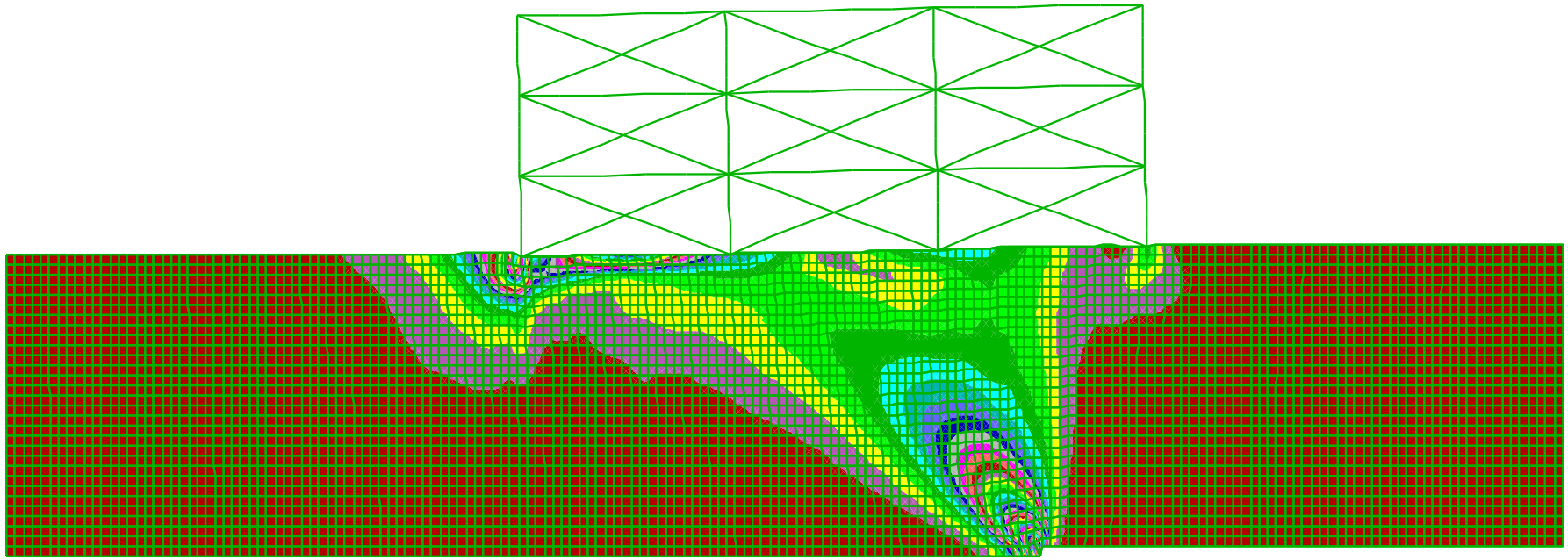
Mat Thickness
= 4 ft



Oettle and Bray (2013)

Mitigation with Superstructure Strength & Stiffness

Stiffer building modifies the structural response

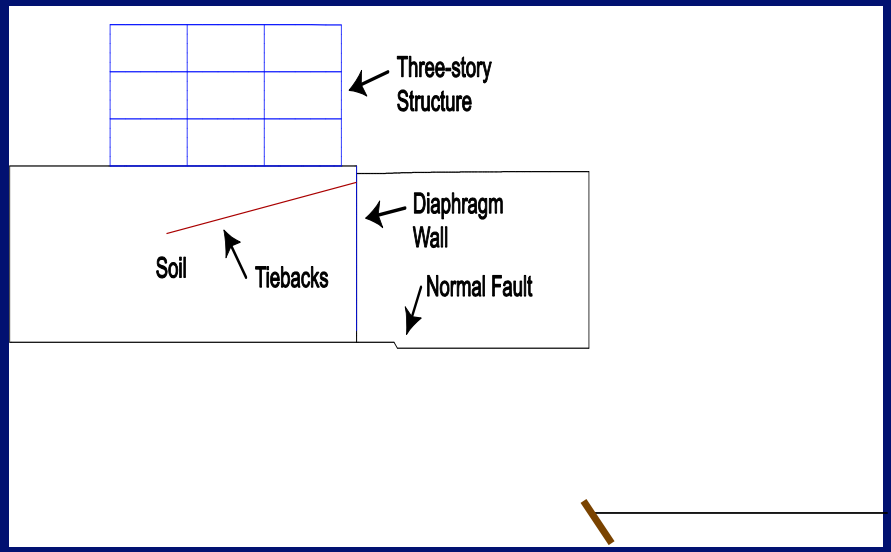


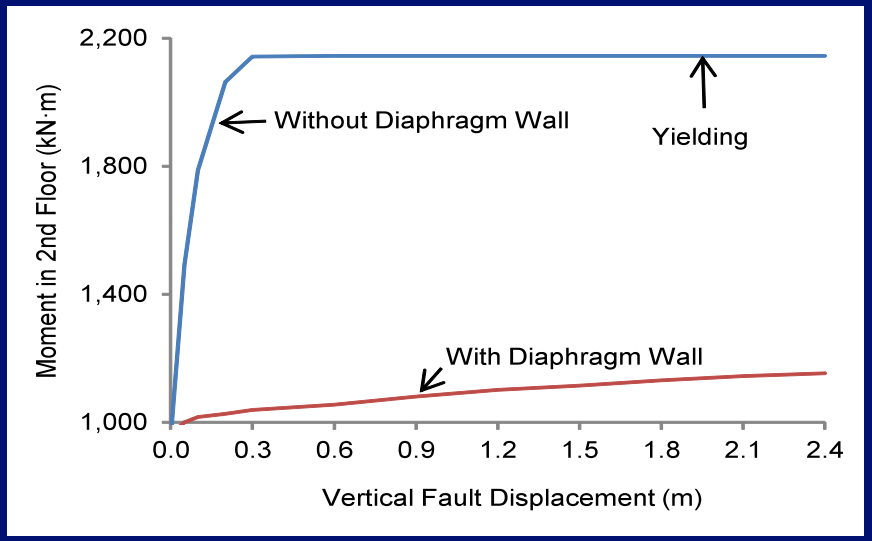
(Oettle & Bray)

Structural Response to Chi-Chi Fault Rupture

Mitigation with Diaphragm Wall

Retaining wall provides support for foundation soil





(Oettle & Bray 2013)

SURFACE FAULT RUPTURE MITIGATION MEASURES

GEOLOGY

- Identify faults and establish non-arbitrary setbacks
- Estimate amount and type of potential fault displacement

GEOTECHNICAL

- Construct ductile reinforced soil fills to spread out movement
- Use slip layer to isolate ground movements from foundation
- Place compressible materials adjacent to walls and utilities

STRUCTURAL

- Design strong, ductile foundations, with flexibility
- Avoid the use of piles

CALIFORNIA MEMORIAL STADIUM RETROFIT

Hayward Fault

Lead & SE: Forell/Elsesser Engineers, Inc. (David Friedman, Rene Vignos, et al.)

GE & Geologists: AMEC Geomatrix (Donald Wells, Bert Swan, Jim French, et al.)

Other Designers:, HNTB, Studios, WSP Flack + Kurtz, & Bellecci & Assoc.

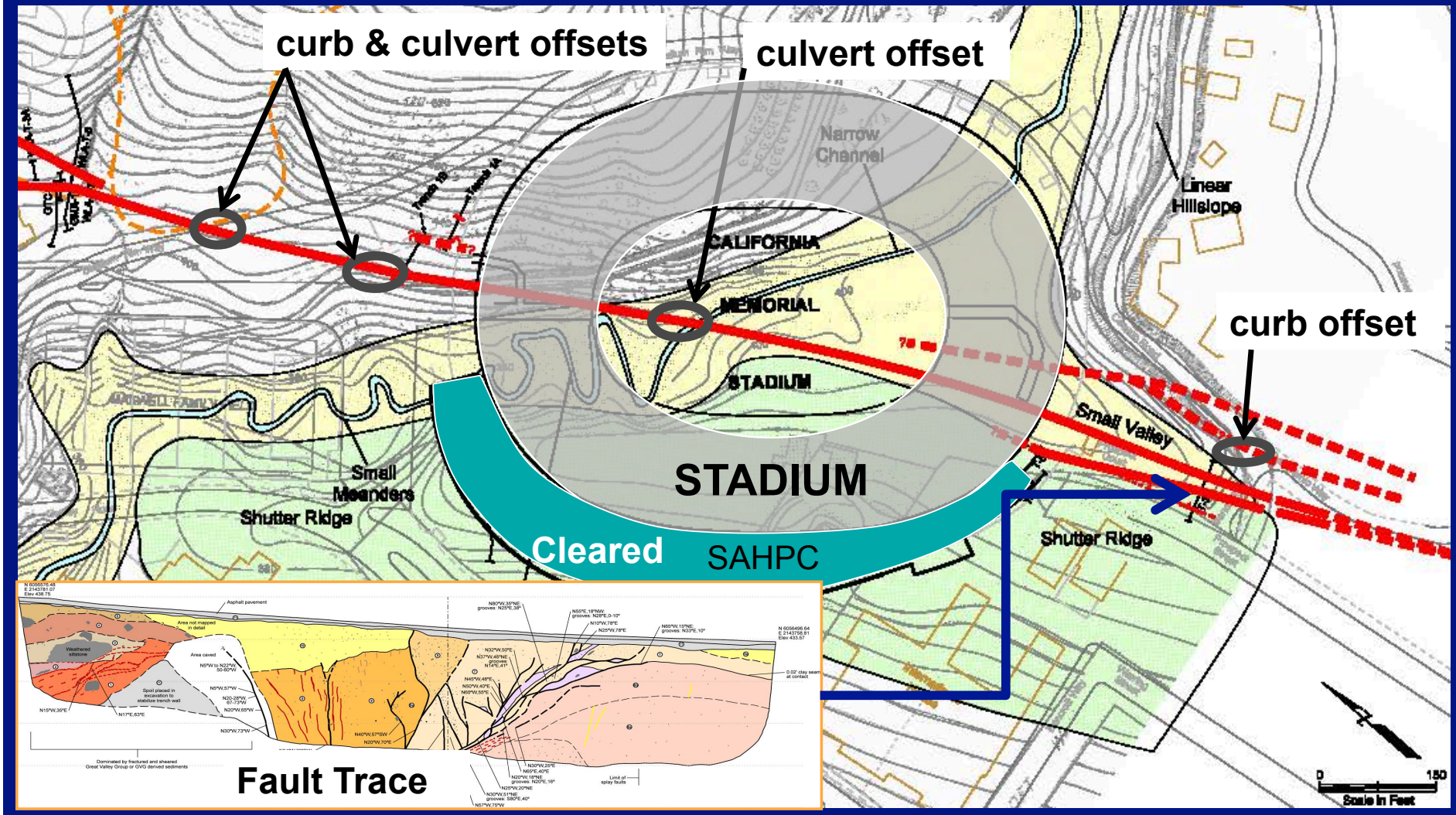
UCB: Ed Denton, Bob Milano, Stan Mar, & Brian Main; General Contractor: Webcor Builders

Independent Peer Reviewers: Loring Wyllie of Degenkolb Engineers & John Baldwin of WLA

UCB Seismic Review Com.: J. Bray, N. Sitar, C. Comartin, J. Moehle, F. Filippou, & Others

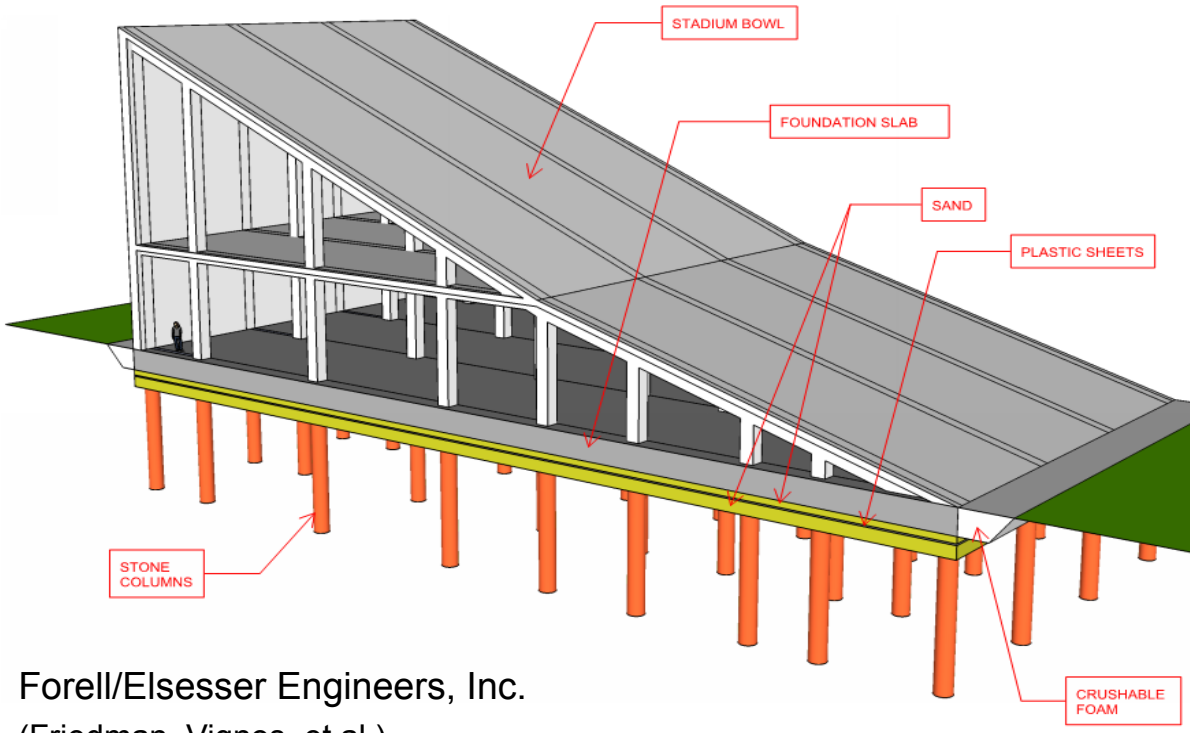
CHARACTERIZING HAYWARD FAULT

AMEC Geomatrix (Wells , Swan, et al.)

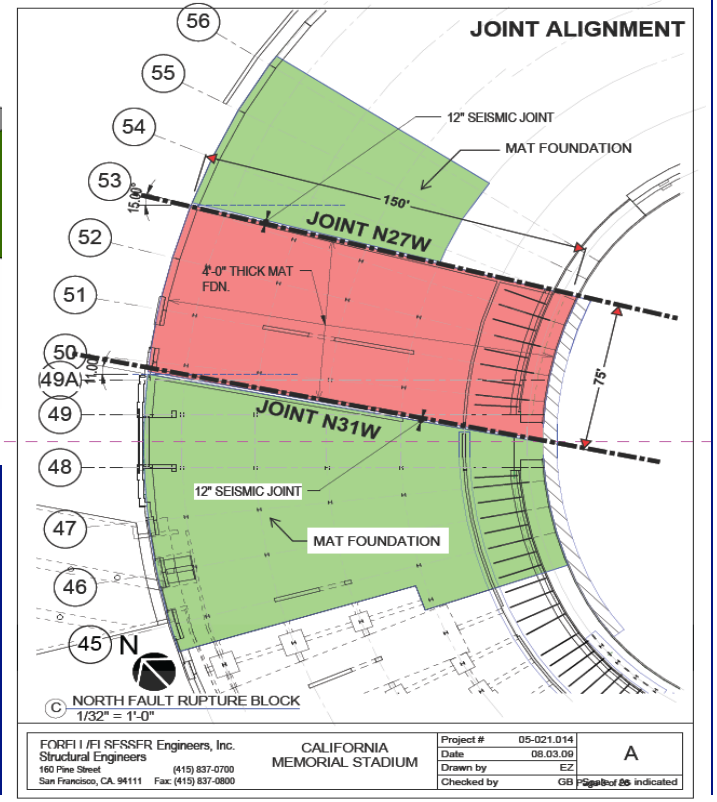


UCB Seismic Review Committee(Bray, Sitar, Comartin, Moehle, et al.) Forell/Elsesser Engineers, Inc. (Friedman, Vignos, et al.)

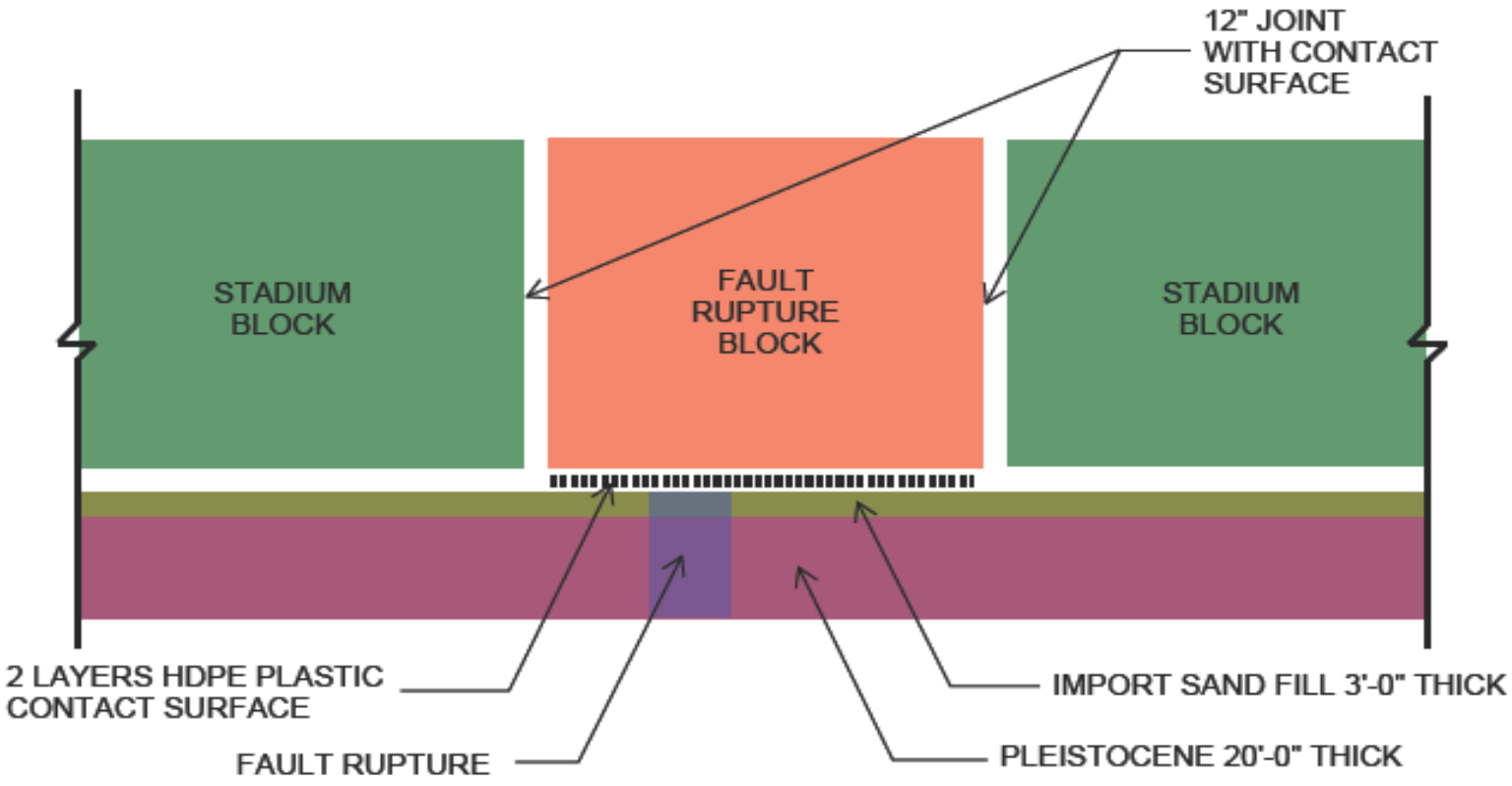
Fault Rupture Block



Forell/Elsesser Engineers, Inc.
(Friedman, Vignos, et al.)



Design Concepts

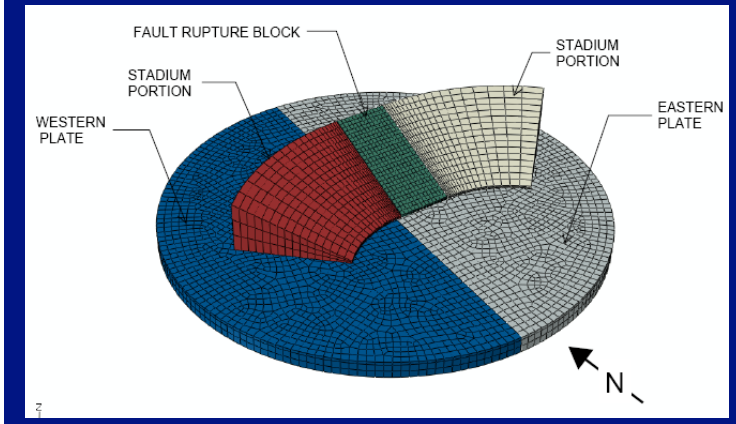


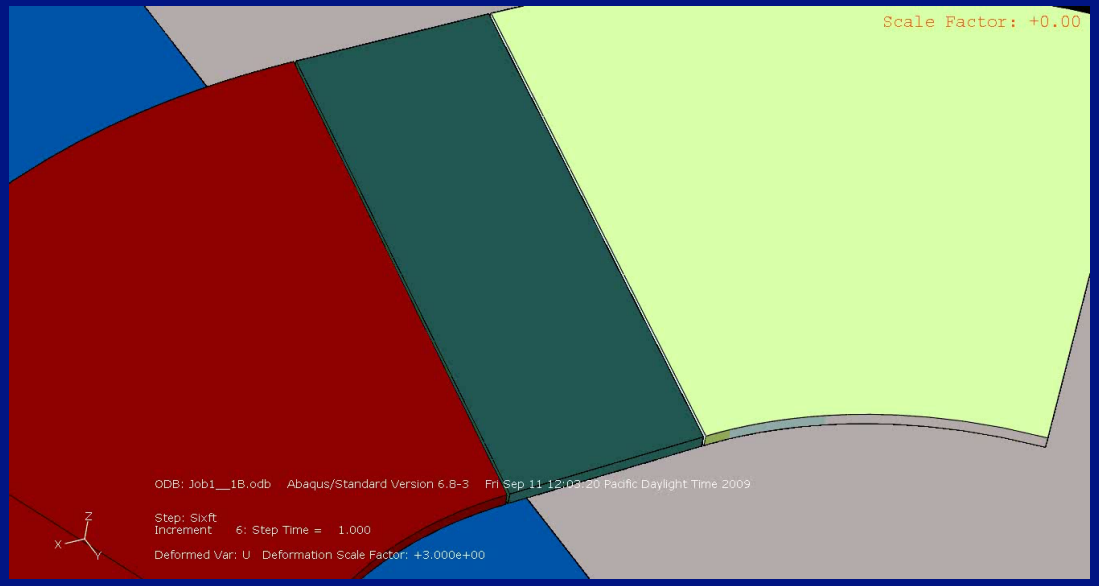
UCB Seismic Review Committee
(Bray, Sitar, Comartin, Moehle, et al.)

AMEC Geomatrix
(French et al.)

Forell/Elsesser Engineers, Inc.
(Friedman, Vignos, et al.)

Response of the Effects of Surface Faulting





Forell/Elsesser Engineers, Inc.
(Friedman, Vignos, et al.)

1972 Alquist-Priolo Geologic Hazard Zones Act

Sect. 2621.5:

"… to provide for the public safety in hazardous fault zones."

Sect. 2622:

"… active traces of the San Andreas, Calaveras, Hayward, and San Jacinto Faults, and such other faults … sufficiently active and well-defined as to constitute a potential hazard to structures …"

Sect. 2623:

"If … no undue hazard exists … structure may be approved."

RETURN TO 1972 PHILOSOPHY

- Not all active faults are hazardous:

  low slip-rate fault with < 2 inch offset vs. high-slip rate fault with > 10 foot offset

- Unintended consequences of current Act

- If we can design for mining subsidence, landslides, & lateral spreading, why not minor fault-induced ground movements?

Does the structure care why the ground moved?

Potential Causes of Ground Movements

A. Expansive Soils

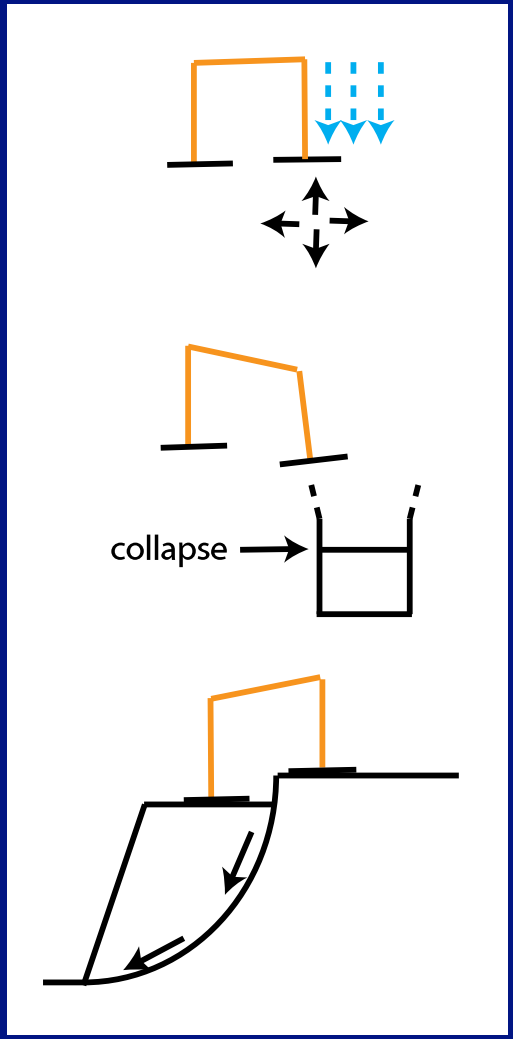
B. Static & Seismic Settlement

C. Mining Subsidence

D. Surface Faulting

E. Landslide

F. Lateral Spreading



Tolerable Levels of Ground Movements

A. **Conventional Construction: b = 1/500, D_t = 1 inch**

B. **Post-Tensioned Slab Residential: b = 1/360, D_t = 1.5 inch**

C. **Liquefaction-Induced Settlement: D_t = 4 inch**

(with “structural mitigation” CGS SP-117A, Youd 1989)

D. **Liquefaction-Induced Horz. Movement: D_t = 12 inch**

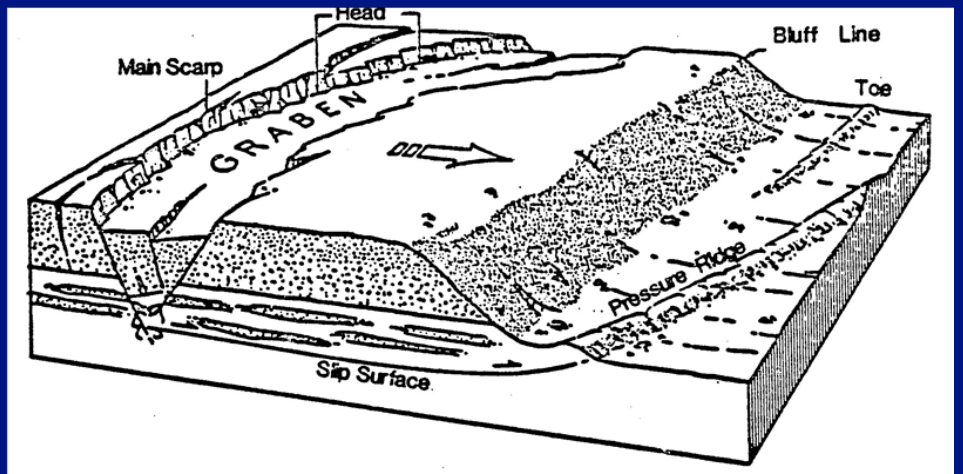
(with “structural mitigation” CGS SP-117A, Youd 1989)

NOT D_t = 0 inch

Anchorage Courthouse

Craig Comartin, SE, Coffman Engineers
(now with CDComartin, Inc.)

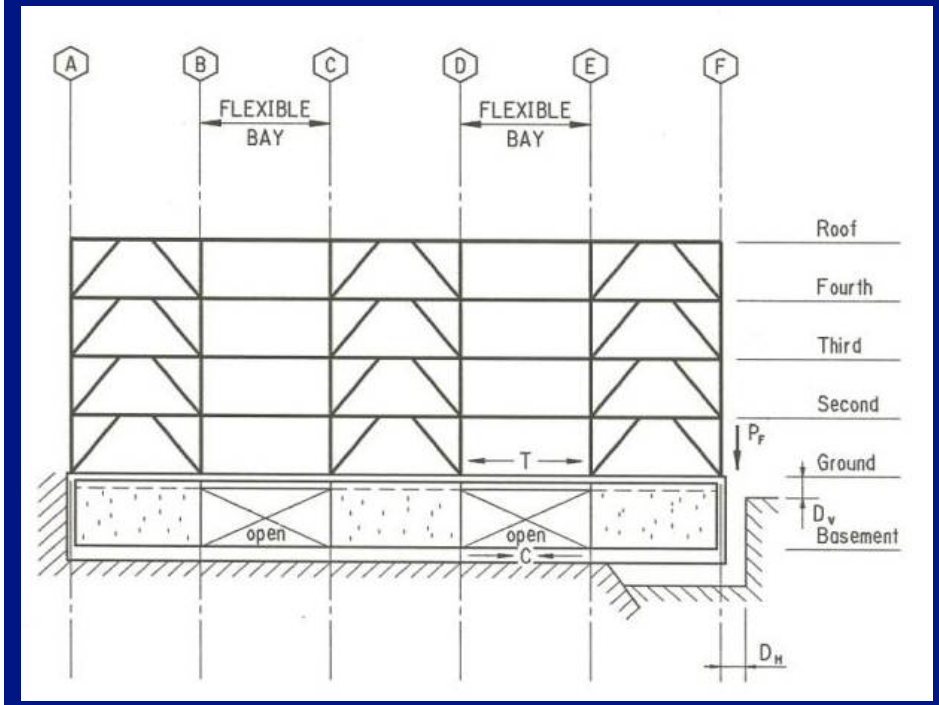
Also:
Idriss & Moriwaki, Woodward-Clyde
H. Shah, Stanford Univ.



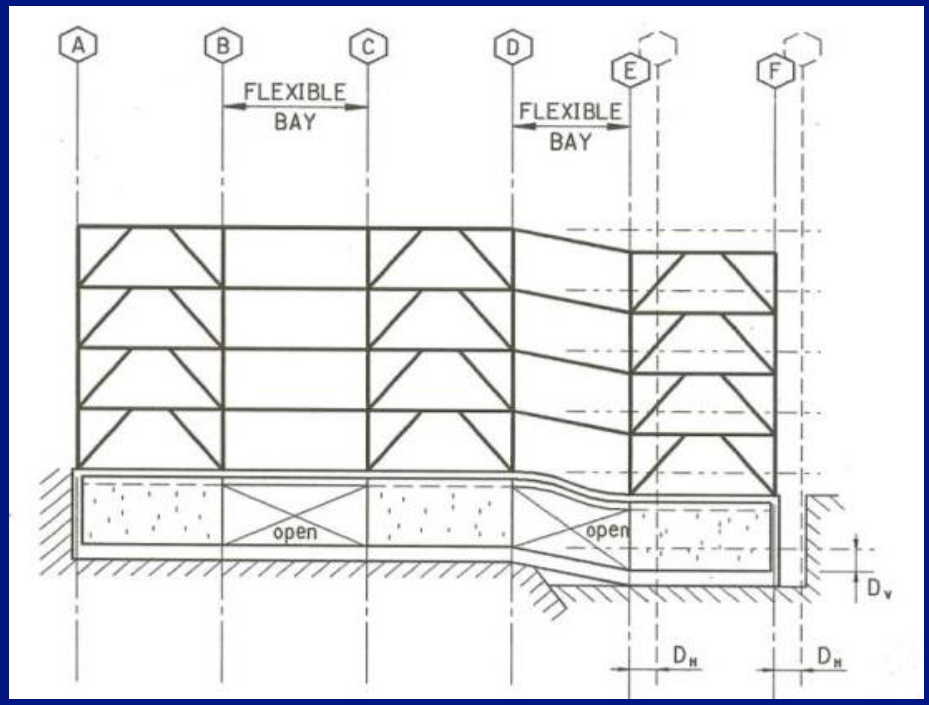
Translatory Block Slide
(Modified after Hansen, Ref. 7)

Anchorage Courthouse: Structural System

Stiff Bay's "Cantilever" Response



Flexible Bay's "Deformed" Response



D_H = 48 in. D_V = 32 in.

Craig Comartin, SE, CDComartin, Inc.

California State Mining and Geology Board

Alquist-Priolo Technical Advisory Committee

DRAFT RECOMMENDATIONS:

Focus on active faults that could produce significant differential ground movement that would constitute a hazard to structures:

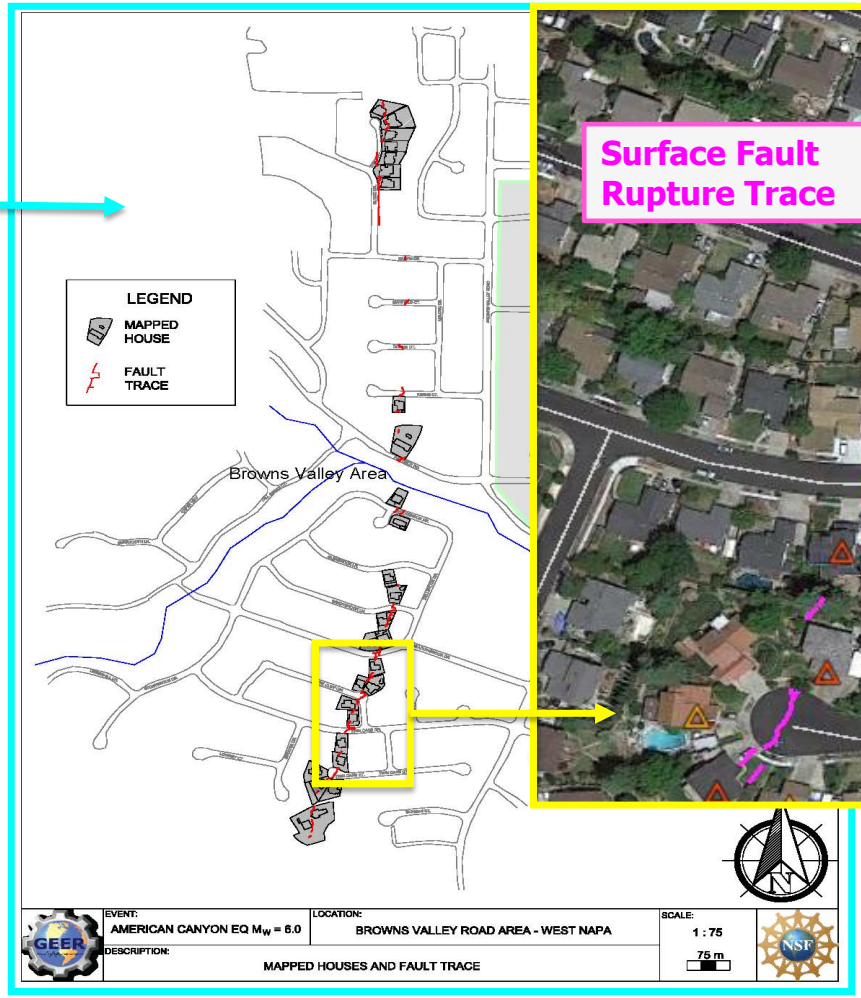
Vert. D_t = 4 in. or Horz. D_t = 12 in. over 10 ft-wide zone,

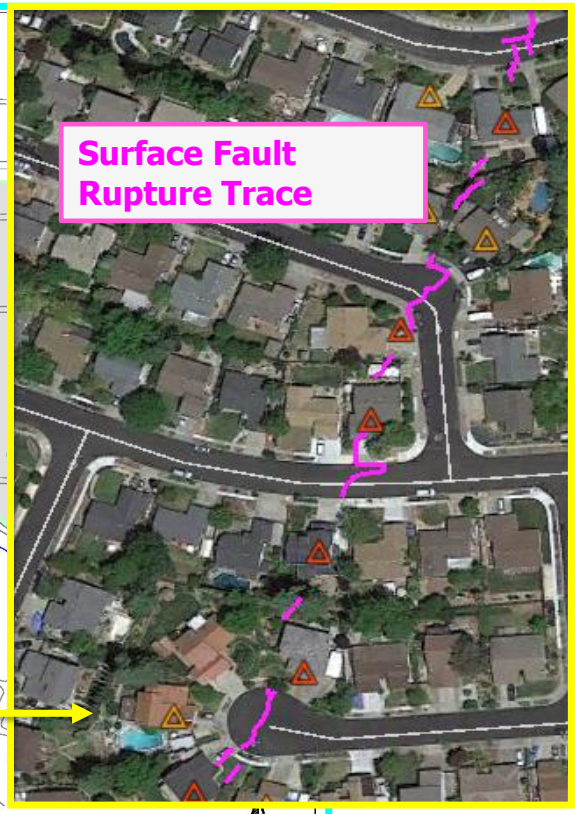
or

Vert. D_t = 8 in. or Horz. D_t = 24 in. across the structure

South Napa Earthquake Surface Fault Rupture

Bray, J., Cohen-Waeber, J., Dawson, T., Kishida, T., and Sitar, N., Editors (2014) GEER Report 037





[NSF-GEER Brown's Valley Recon. Teams; 8/25/14 – 8/28/14]

Surface Fault Rupture Damage to Homes

Cracked garage slab

Cracked strip footing and tilted cripple stud wall

Pushed 4.5 in off foundation

Documented 27 homes affected by surface rupture

Key Observations:

- Average observed deformation: 4 to 5 inches
- No life safety issue resulted from surface faulting
- Unreinforced concrete slabs cracked and reinforced slabs slid uniformly or tilted
- Structures on pier foundations more heavily damaged
- Seismically retrofit homes/new construction performed best

Rupture through piers

Damage to structure

CONCLUSIONS

- Surface faulting is affected by:
  - fault characteristics
  - overlying soil
  - foundation & structure

- Surface fault rupture can be analyzed and mitigated similar to other ground movement hazards, e.g., landslides & mining subsidence

GEOLOGIC DATA NEEDS FOR ENGINEERING MITIGATION OF LIQUEFACTION HAZARDS

Ross Boulanger
University of California, Davis

The following is a PDF version of the author's PowerPoint presentation.

Utah Geological Survey

Basin and Range Province Seismic Hazards Summit III, Jan 12-17, 2015

Geologic Data Needs for Engineering Mitigation of Liquefaction Hazards

UC DAVIS
UNIVERSITY OF CALIFORNIA

Ross W. Boulanger

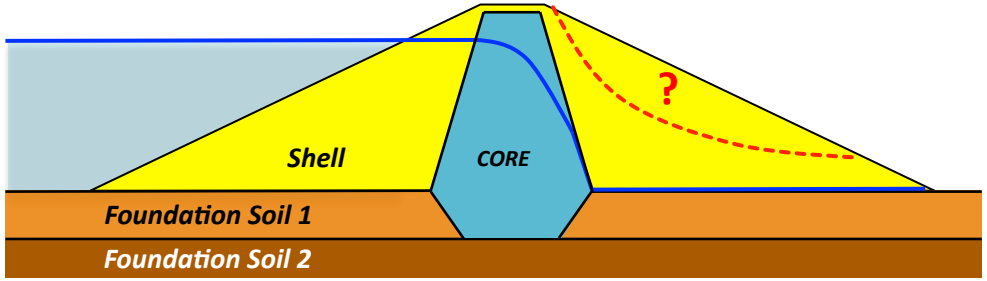
Professor

Geologic data needs

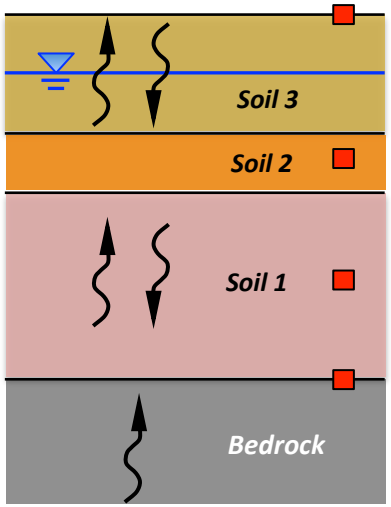
- ***Geologic data needs depend on:***
  - ***The nature of the soil or soil-structure system, potential failure modes, consequences of poor performance, and the decisions that eventually will need to be made***
  - ***Analysis models and their parameters***
- ***Geology guides and/or informs:***
  - ***Identification and awareness of hazard***
  - ***Development of analysis models***
  - ***Interpretation and selection of analysis parameters – accounting for spatial variability***
  - ***Interpretation of in-situ tests – accounting for their limitations in specific subsurface conditions***
  - ***Evaluation of remediation alternatives – accounting for constructability issues in specific subsurface conditions***

Example problems & analysis models

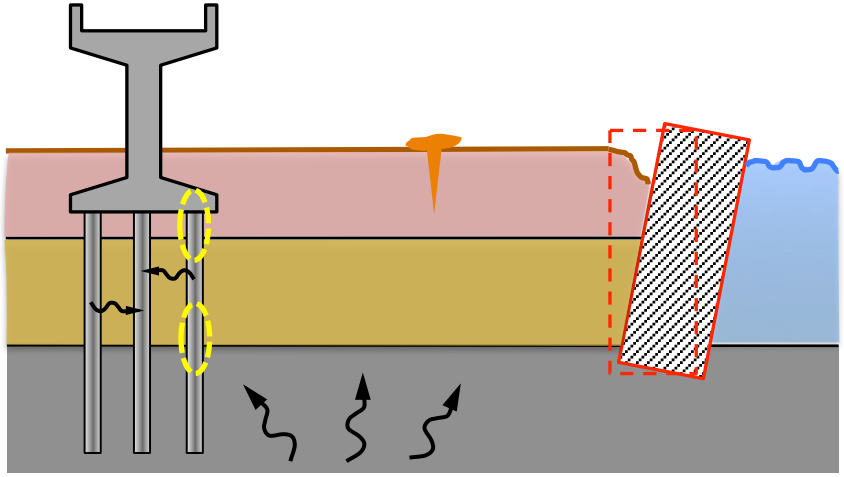
Problem specific challenges



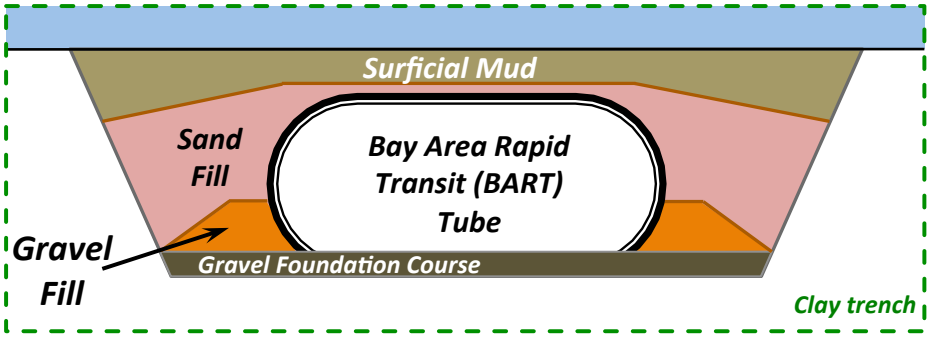
Embankment Dam



1D Site Response Analysis



Soil-Pile-Quay Wall Interaction



Tunneling – Soil-Structure Interaction

Slide courtesy of K. Ziotopoulou

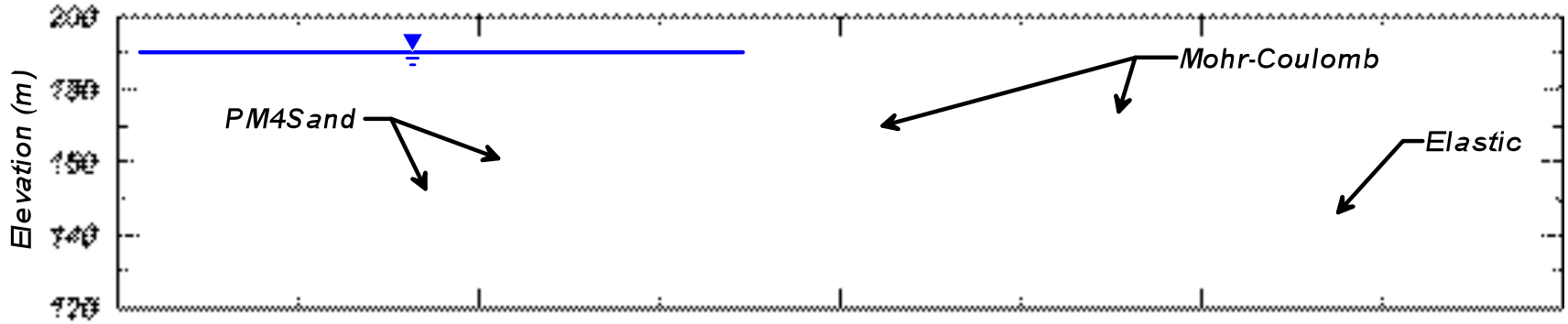
Simplified approaches

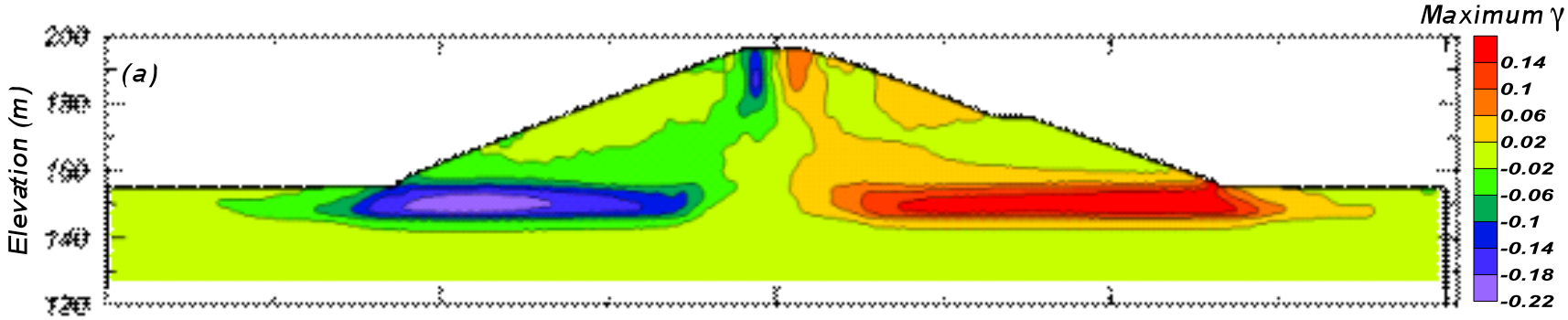
- *Simplified approaches for lateral spreading or 1D settlement are not easily generalized to soil-structure system problems*
  - *Empirical regression models*
  - *Newmark sliding block analyses*
  - *Integration of potential strains versus depth; e.g., LDI, LPI, LPI_{ISH}, LDI, LSN, S_{v1D}*

Kocaeli earthquake (from GEER 1999)

Nonlinear deformation analyses

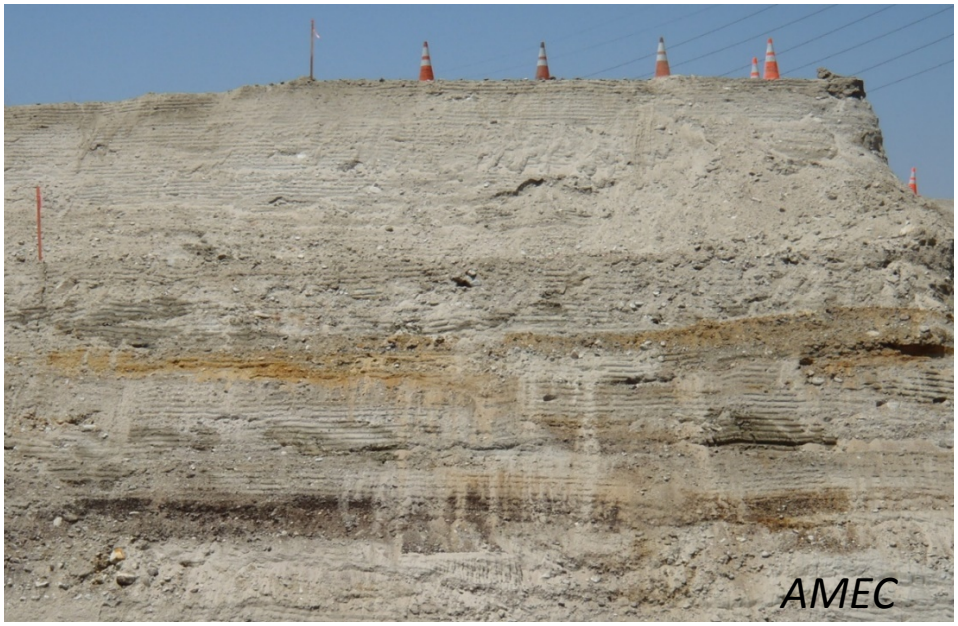
- *NDAs increasingly common on larger projects*
- *Zones and strata assigned "representative" properties*





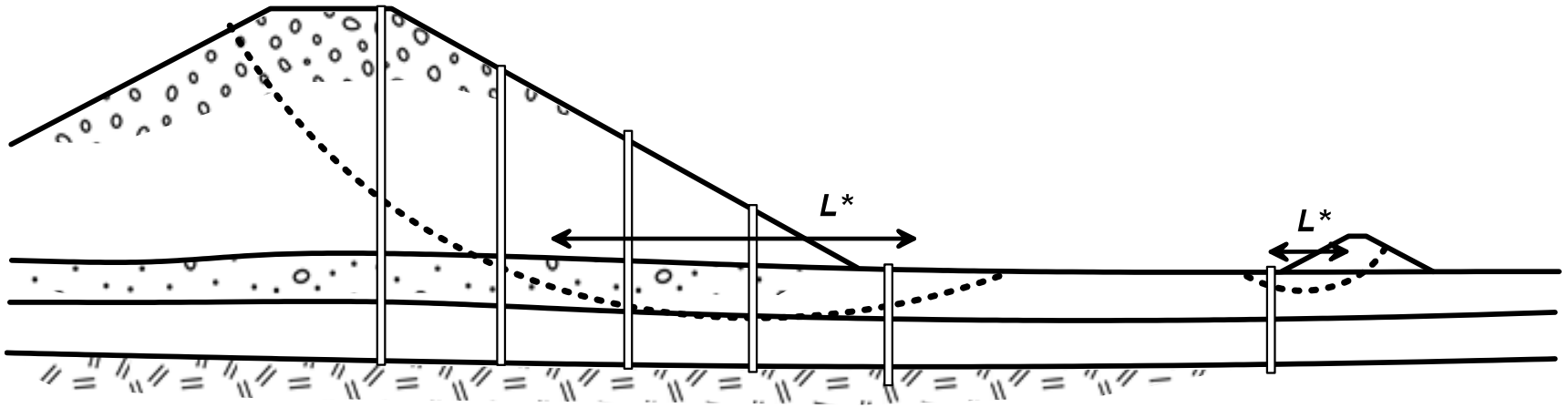
Selecting modeling properties: Accounting for spatial variability

Scale of variability



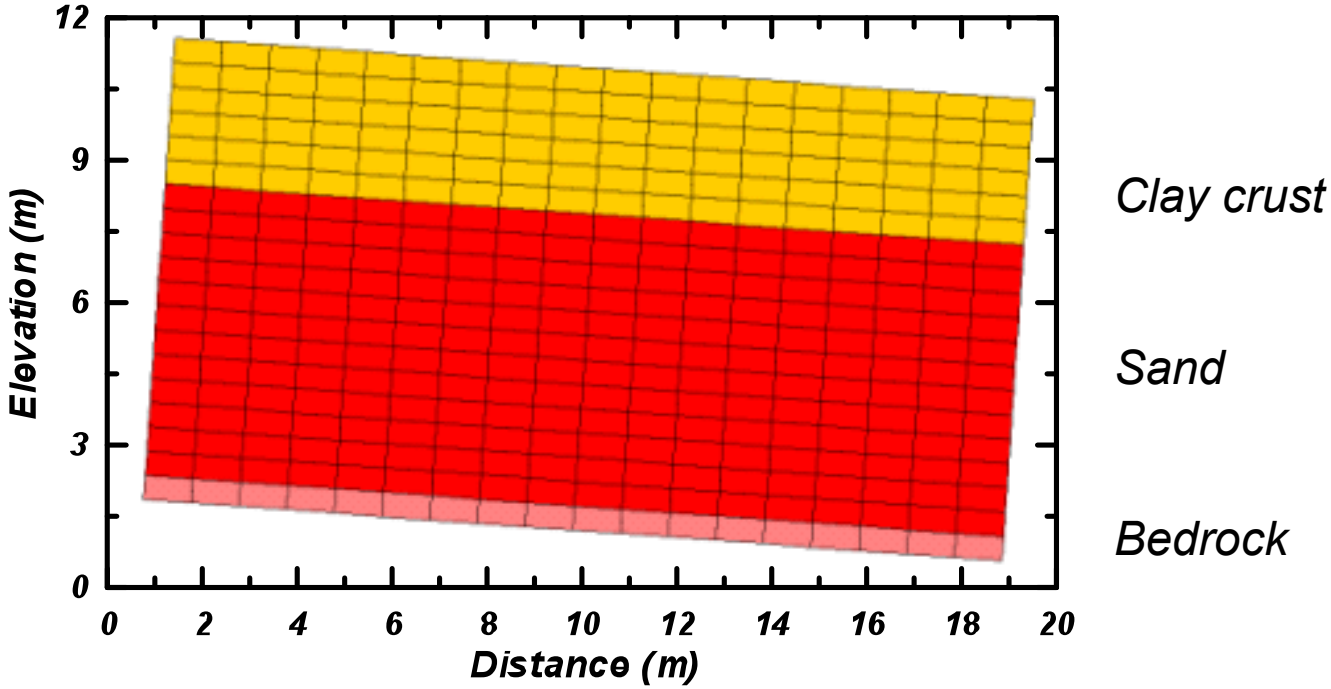
Representative properties

- *Strata in "homogenous" models are assigned "representative" properties intended to produce responses similar to those for "stochastic" models. Representative properties depend on:*
  - *scale of the structure or foundation being analyzed,*
  - *scale of the spatial variability in the stratum, and*
  - *mechanism of deformation.*
- *An additional allowance may be made for uncertainty in the estimated distribution of in-situ properties (i.e., sample size, test quality).*
- *Representative properties are often taken as 30th or 50th percentile values for bins over the scale of the potential failure mechanism.*



What is "representative"?

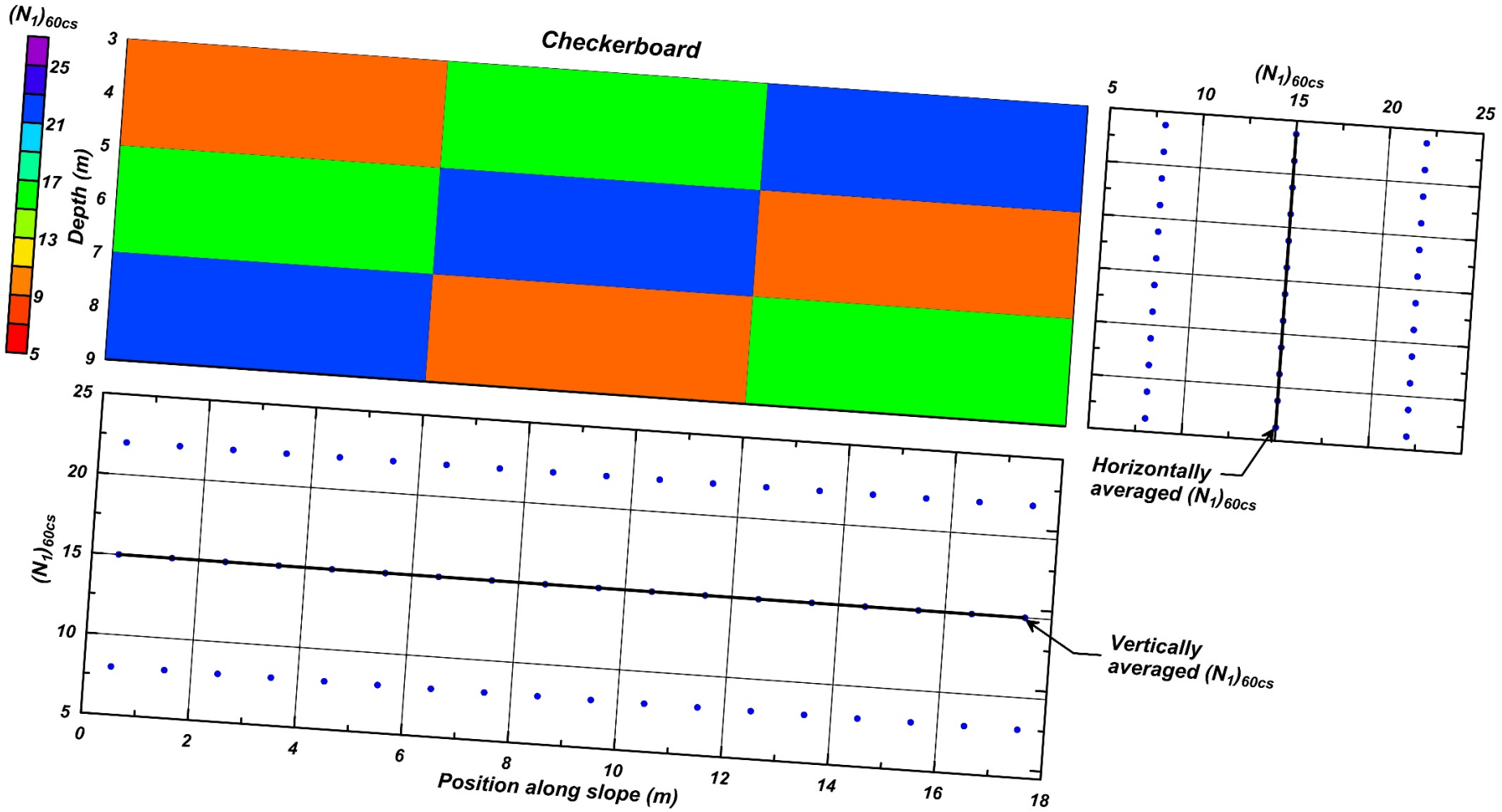
- *Numerical simulations comparing stochastic and homogenous models provide insights on role of variability (e.g., Popescu et al. 1997).*
- *Here we analyze an infinite slope (lateral spread) using FLAC (Itasca) with PM4Sand (Boulanger and Ziotopoulou 2013) for the sand.*



Boulanger and Montgomery (2015)

Homogenous vs checkerboard models

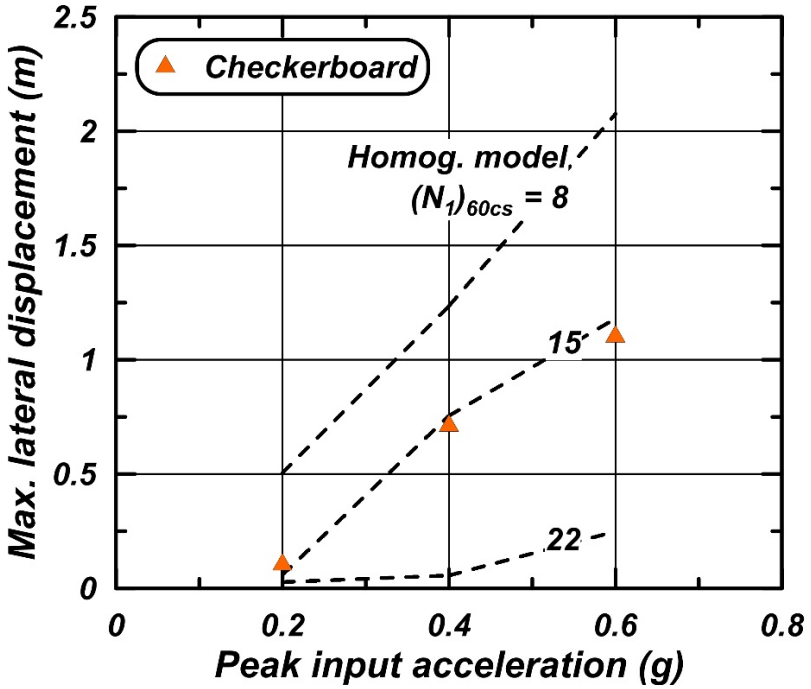
- *Simplest idealized illustration of variability in a lateral spread*

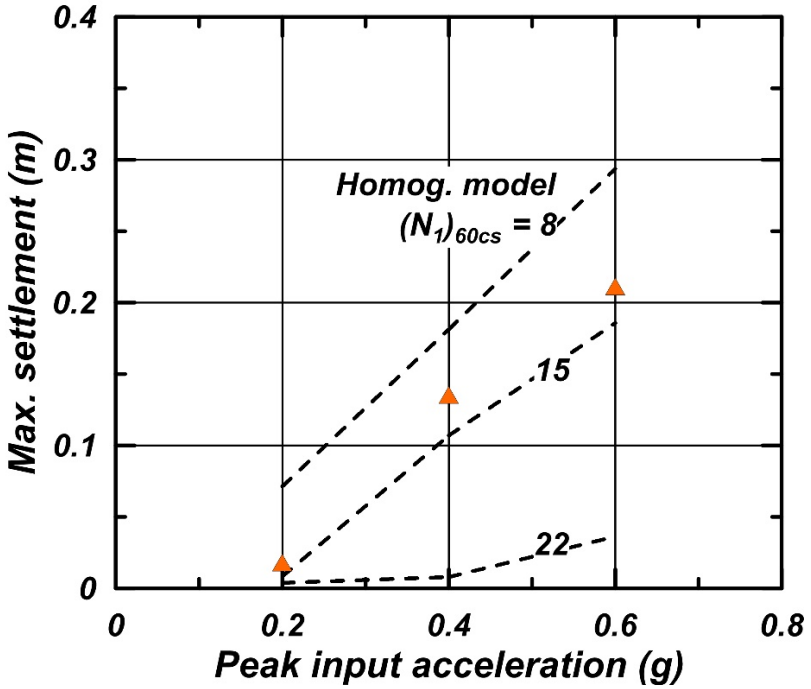


Boulanger and Montgomery (2015)

Homogenous vs checkerboard models

- *Homogenous model with median $(N_1)_{60cs}$ worked well for lateral spreading, but under-estimated settlements.*

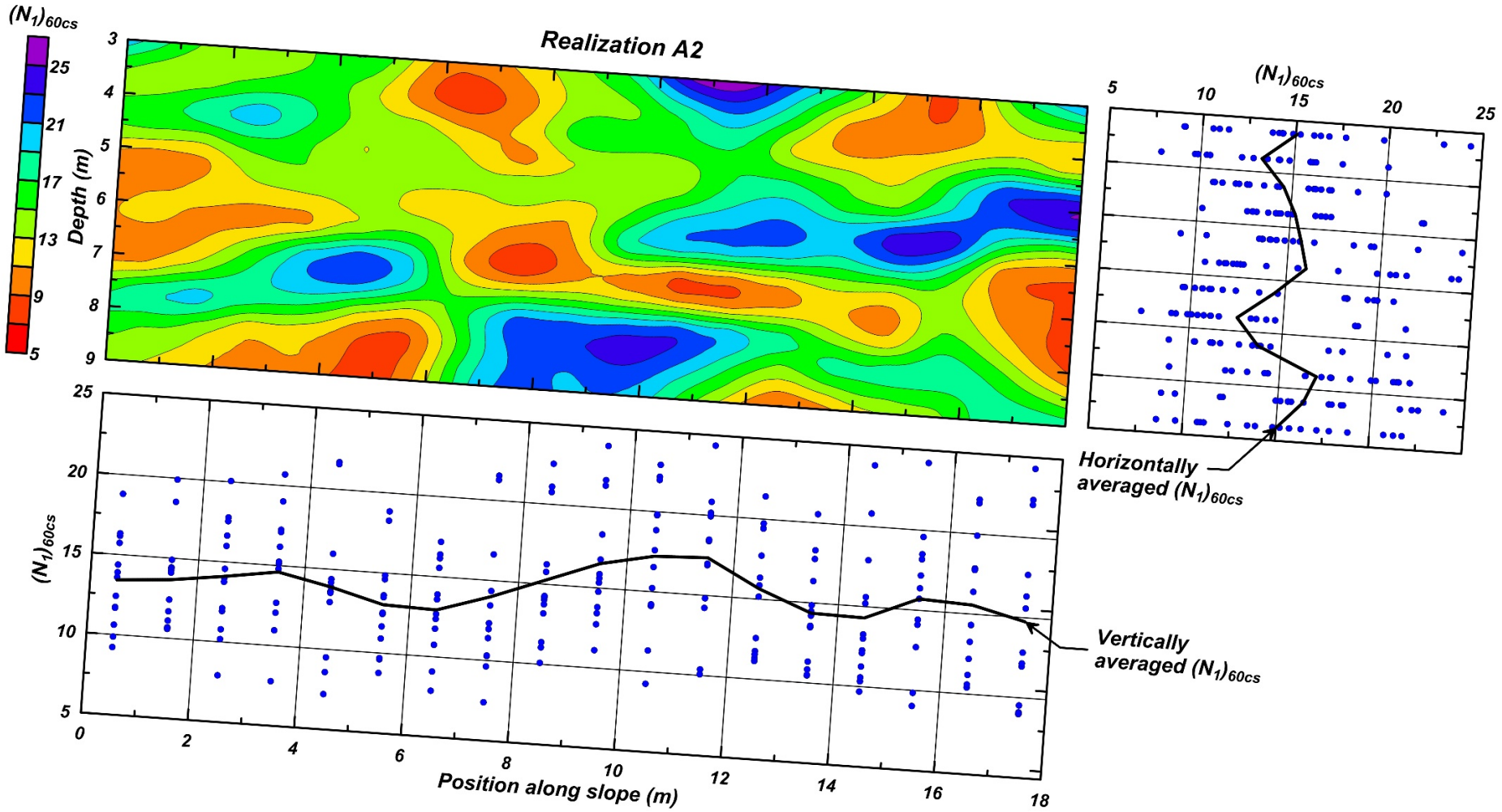




Boulanger and Montgomery (2015)

Homogenous vs stochastic models

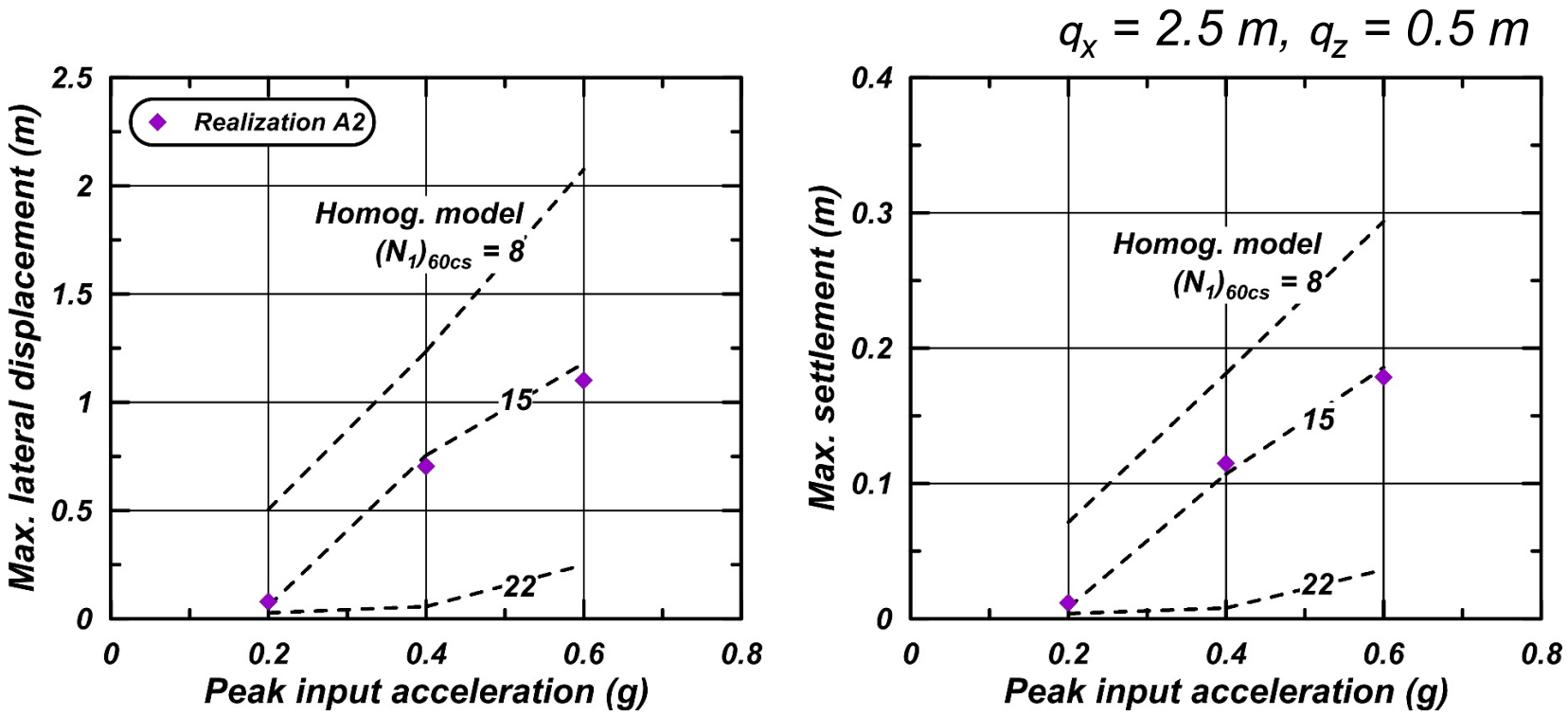
- *Stochastic model with q_x = 2.5 m, q_z = 0.5 m*



Boulanger and Montgomery (2015)

Homogenous vs stochastic models

- *Homogenous model with median $(N_1)_{60cs}$ worked well for lateral spreading, but …*

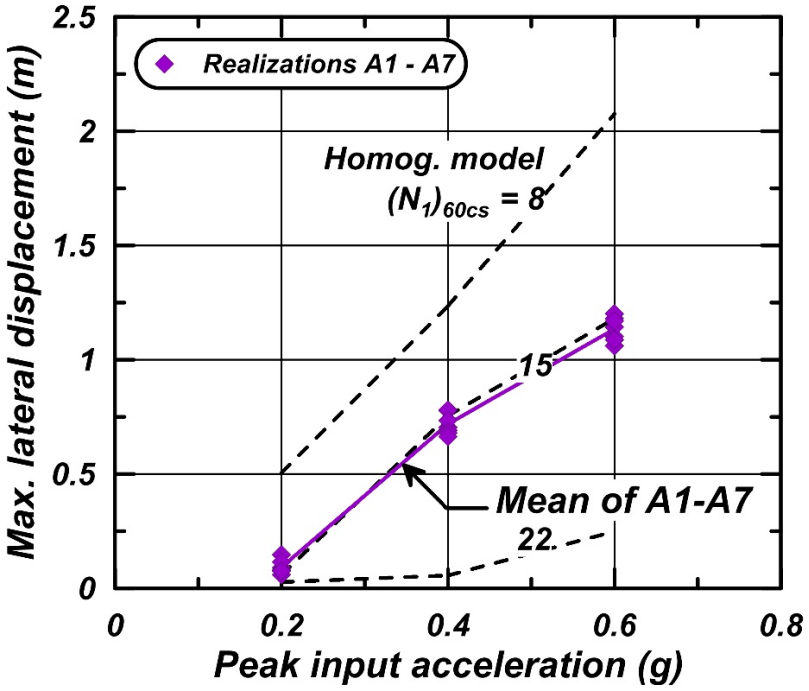


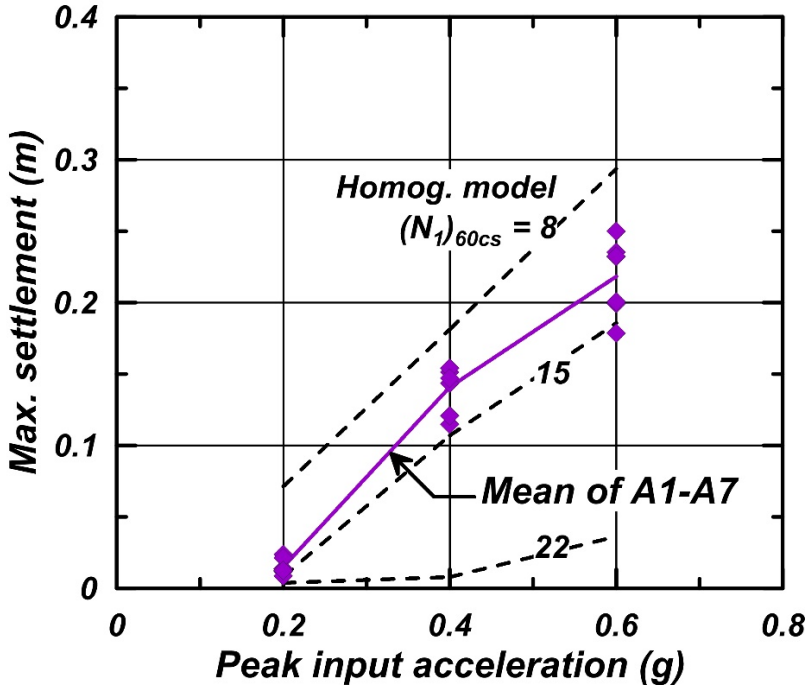
Boulanger and Montgomery (2015)

Homogenous vs stochastic models

- *Homogenous model with median $(N_1)_{60cs}$ worked well for lateral spreading, but under-estimated settlements (particularly for loose pockets near the surface)*

q_x = 2.5 m, q_z = 0.5 m

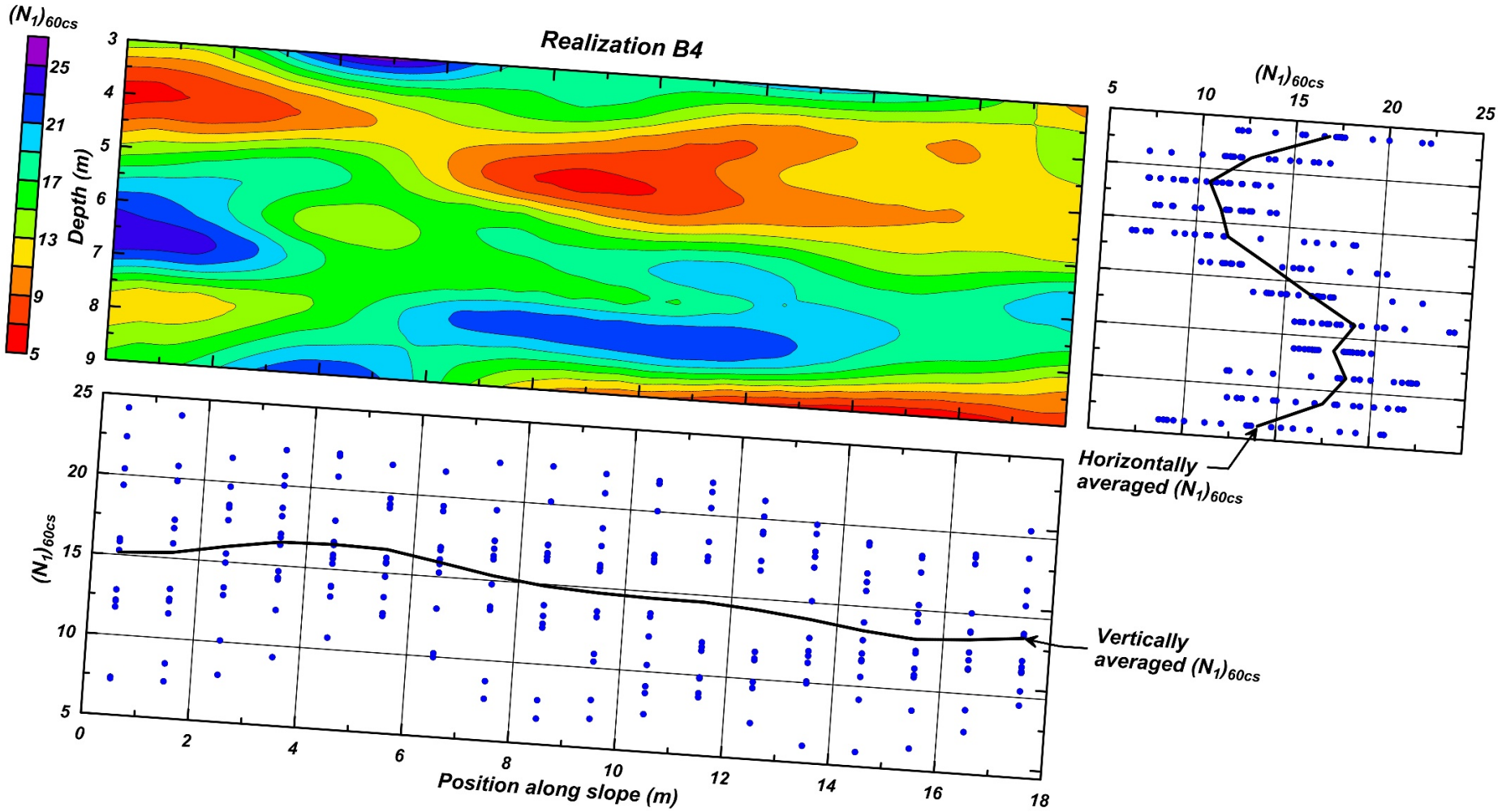




Boulanger and Montgomery (2015)

Homogenous vs stochastic models

- *Stochastic model with q_x = 10.0 m, q_z = 0.5 m*

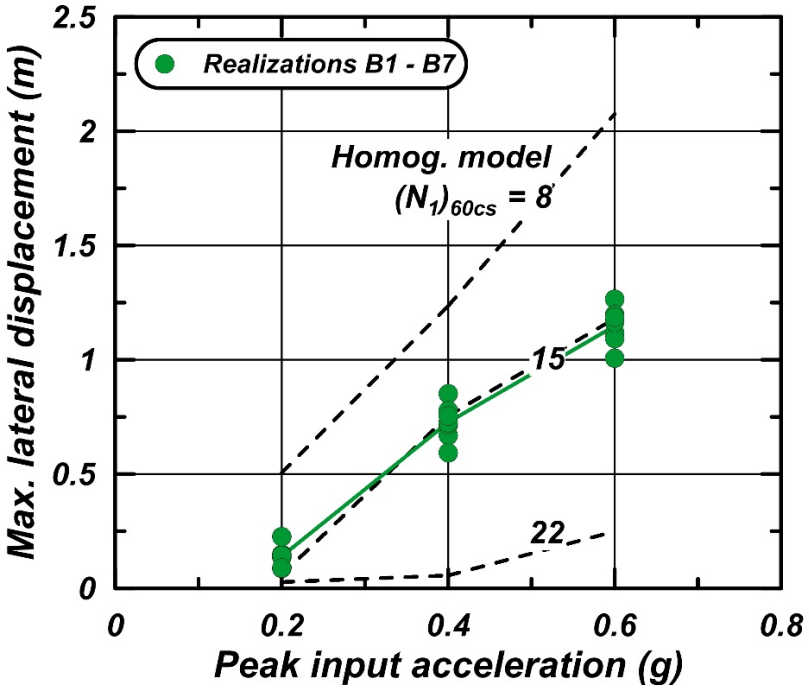


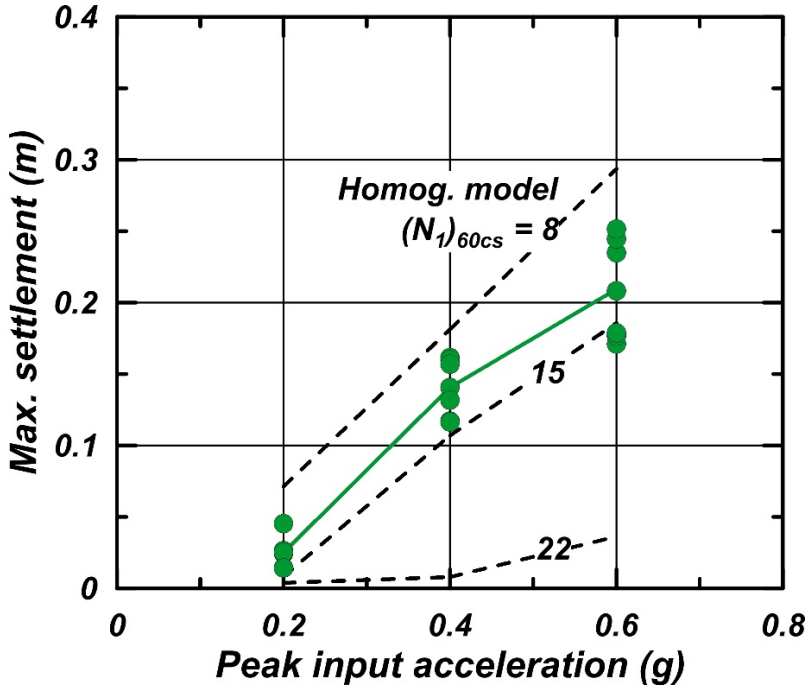
Boulanger and Montgomery (2015)

Homogenous vs stochastic models

- *Homogenous model with median $(N_1)_{60cs}$ worked well for lateral spreading at high PGA, but under-estimated movements at low PGA (due to more continuous looser zones)*

q_x = 10.0 m, q_z = 0.5 m

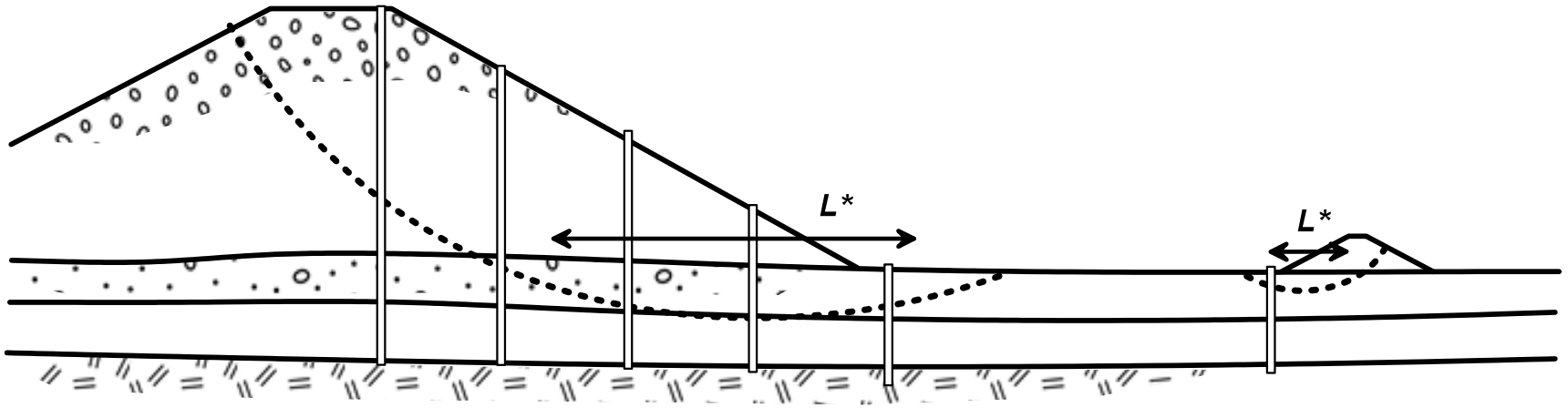




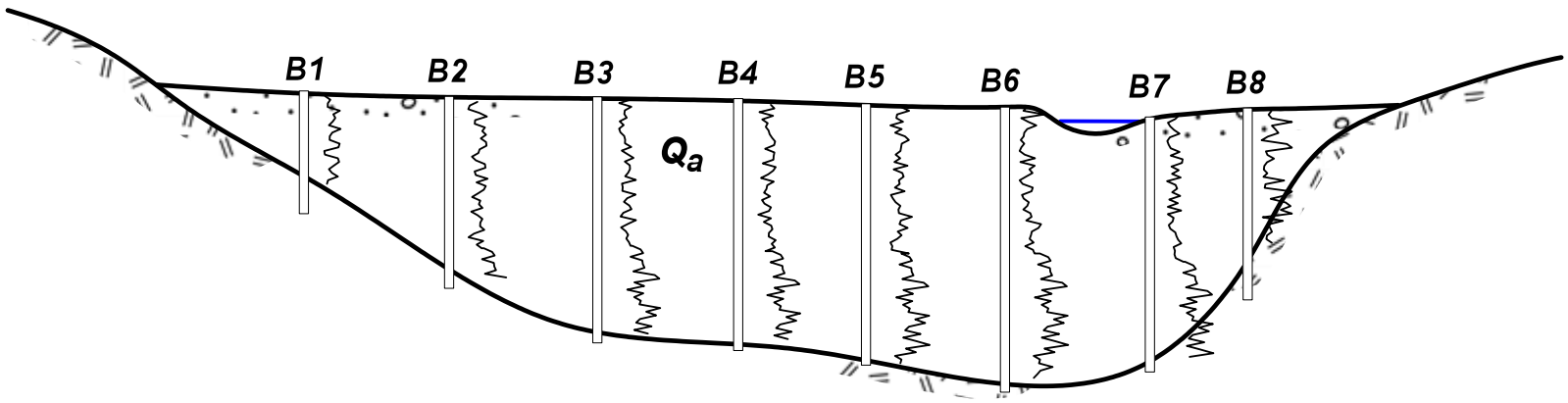
Boulanger and Montgomery (2015)

Representative properties

- *Representative properties can depend on:*
  - *scale of the structure or foundation being analyzed,*
  - *scale of the spatial variability in the stratum, and*
  - *mechanism of deformation.*
- *Small-scale failure mechanisms – can be governed by the lower end of the distributions (the loosest zones, channels, etc).*
- *Large-scale failure mechanisms – can allow for greater averaging of properties (but look out for continuous layers).*



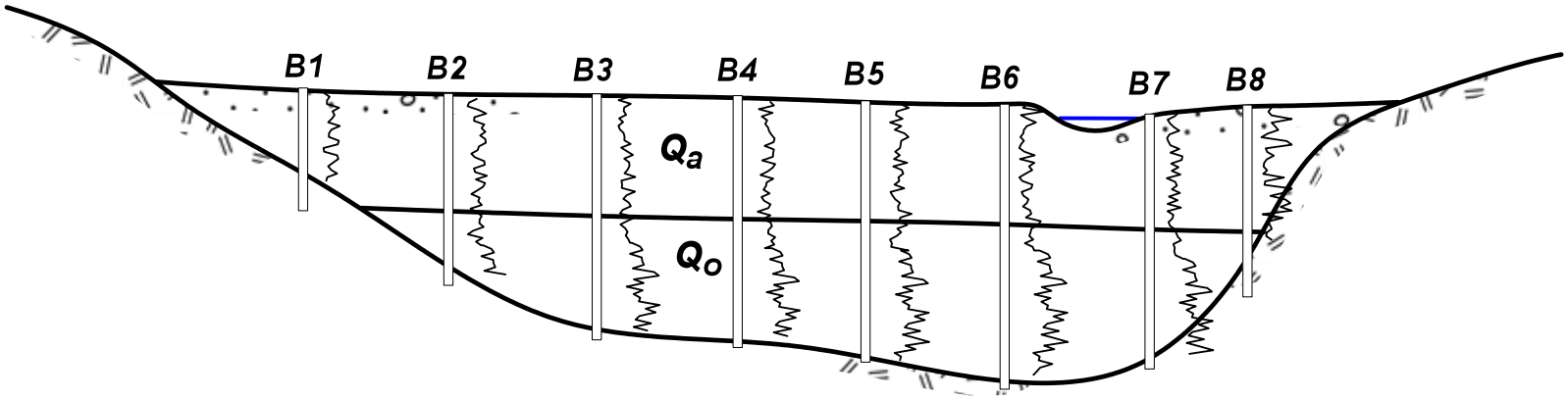
Representative values for "homogenous" units

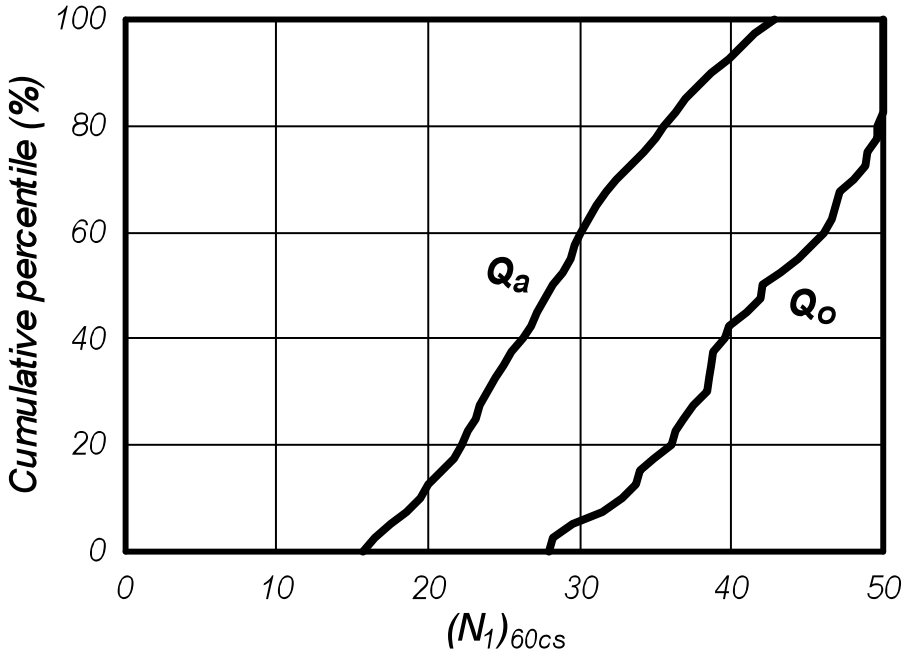


- *Selection of a "representative" value depends on the system, the geology, and the mechanism.*

- *The following slides illustrate an approach for examining data for a large embankment on alluvium for which shear deformations are the primary concern.*

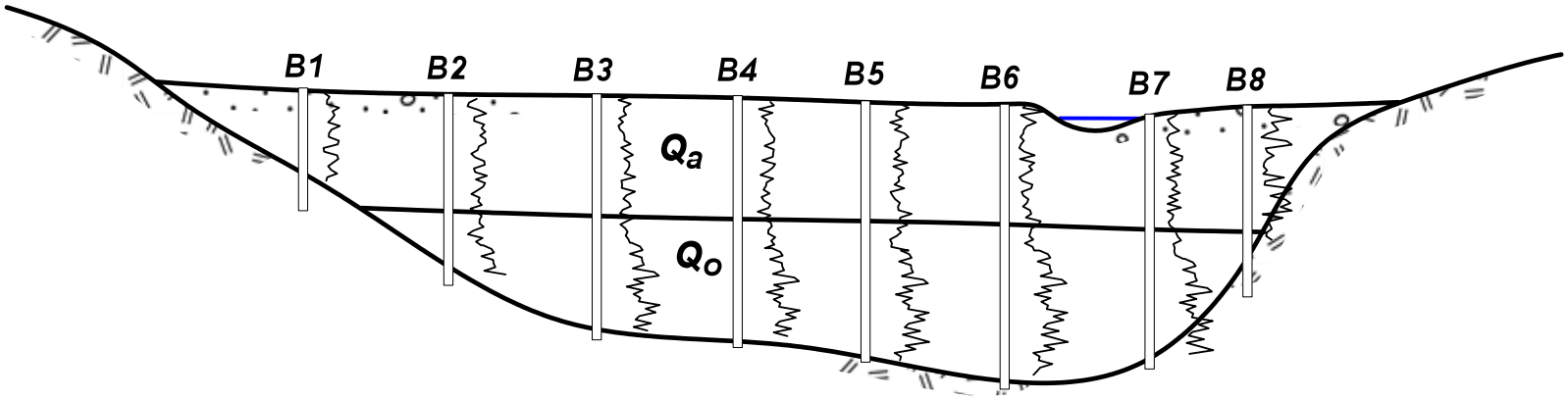
Representative values for "homogenous" units

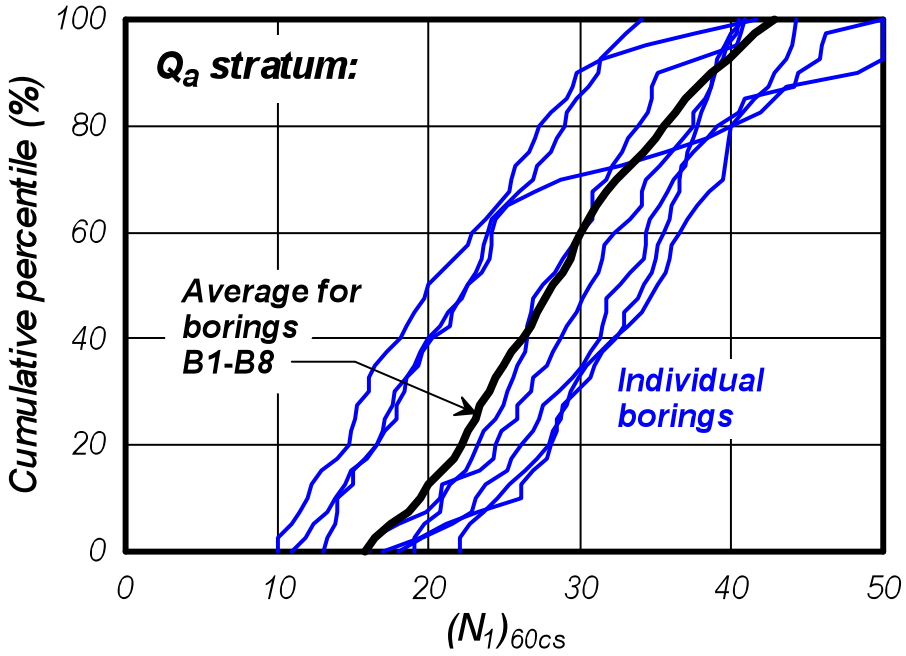




Binning should account for geologic units.

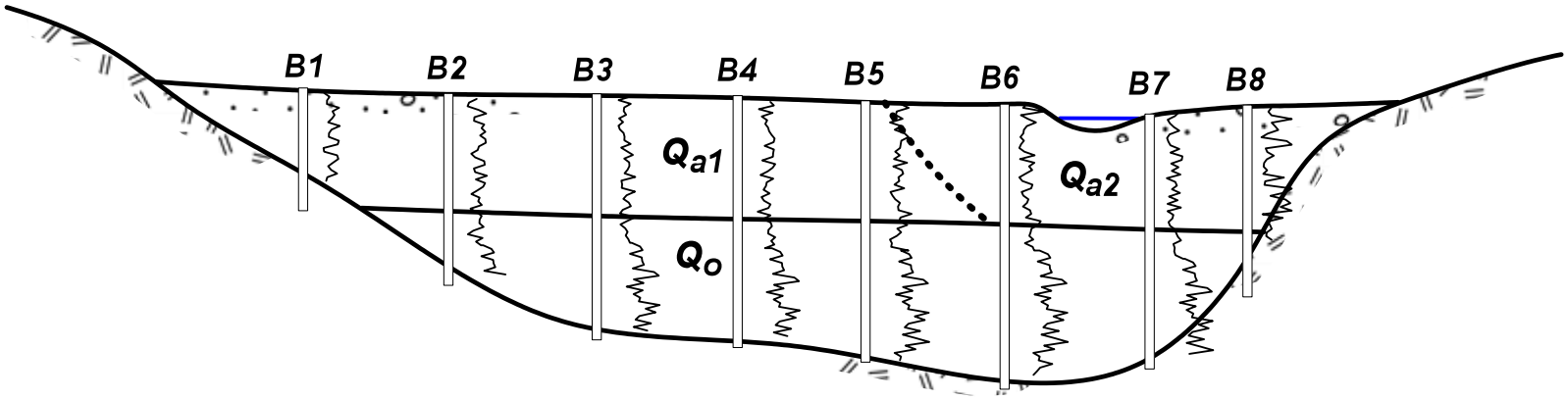
Representative values for "homogenous" units

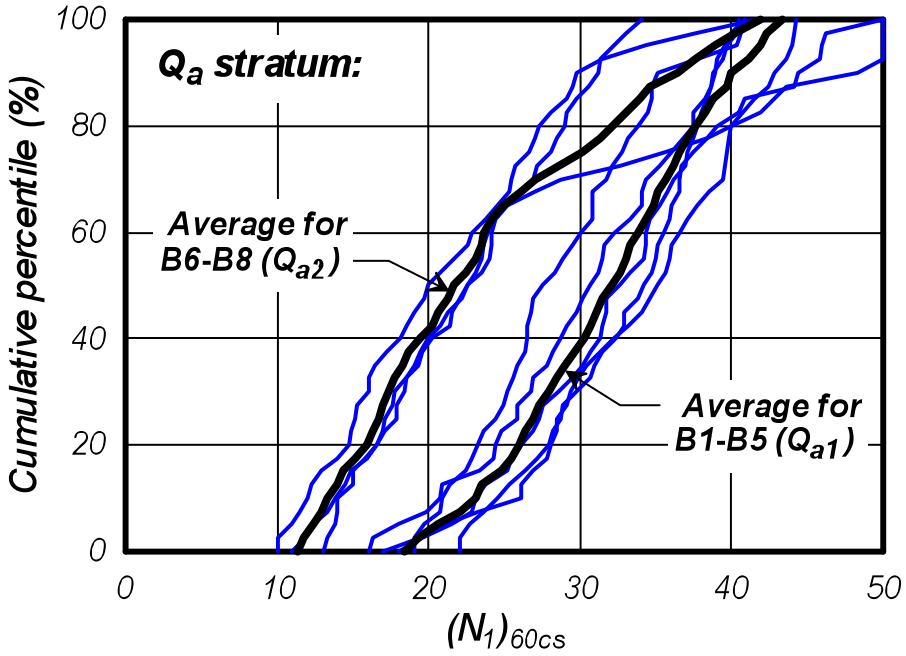




…and for spatial variations in engineering characteristics.

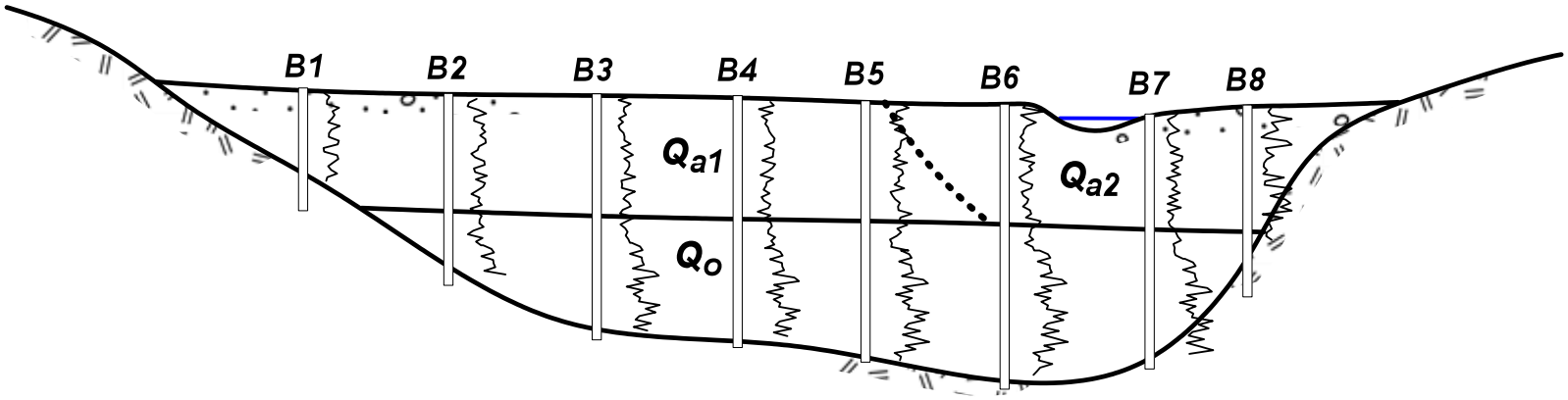
Representative values for "homogenous" units

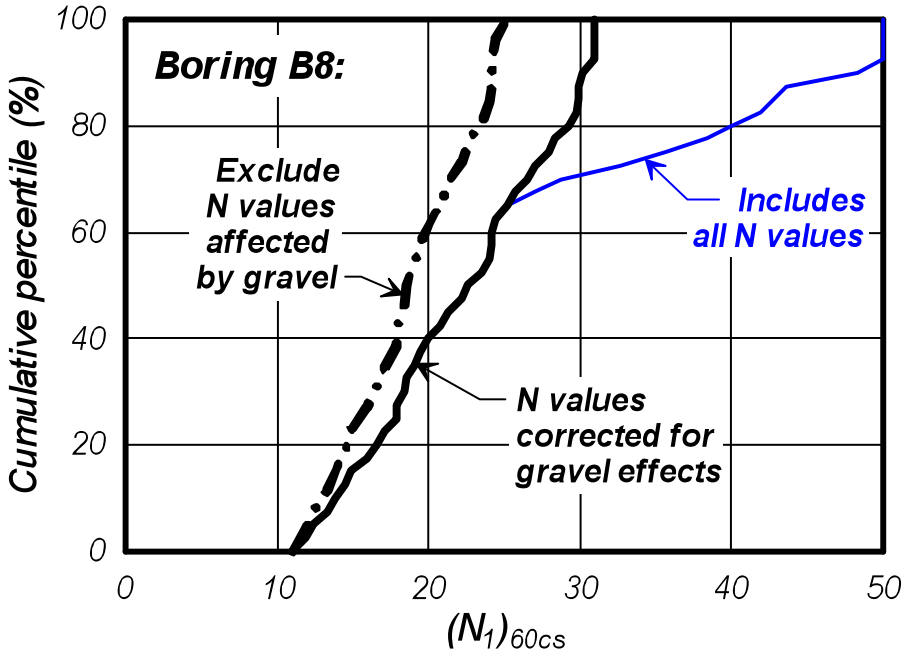




…and for spatial variations in engineering characteristics.

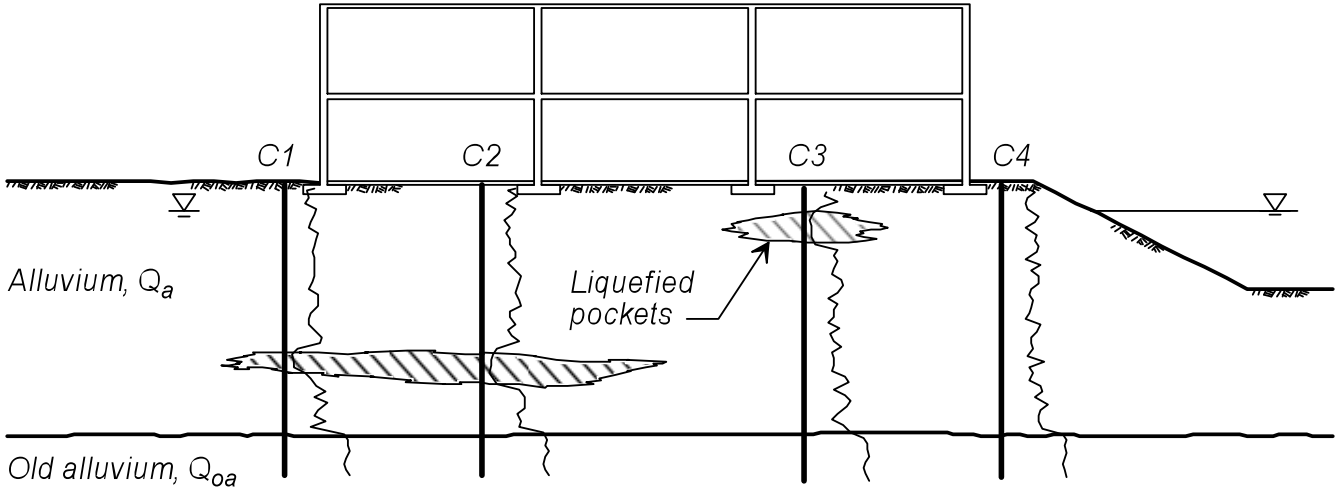
Representative values for "homogenous" units

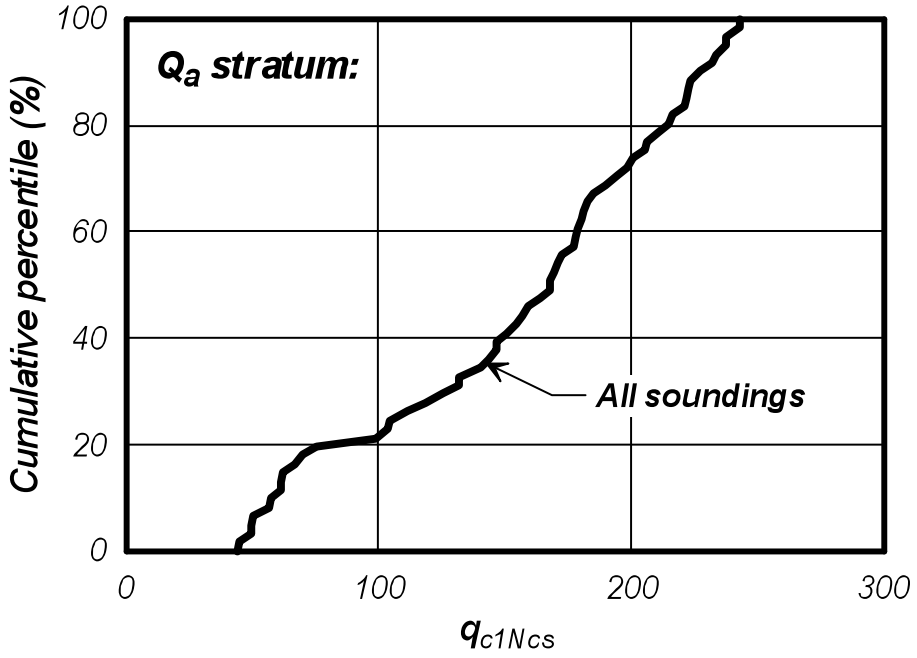




…and for data quality and other issues.

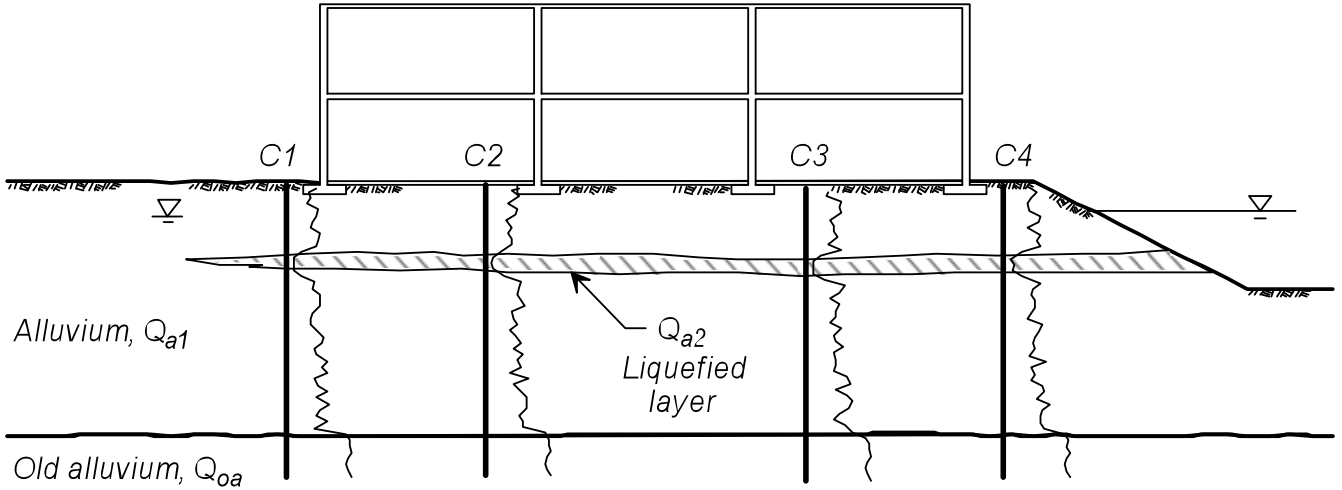
Representative values for "homogenous" units

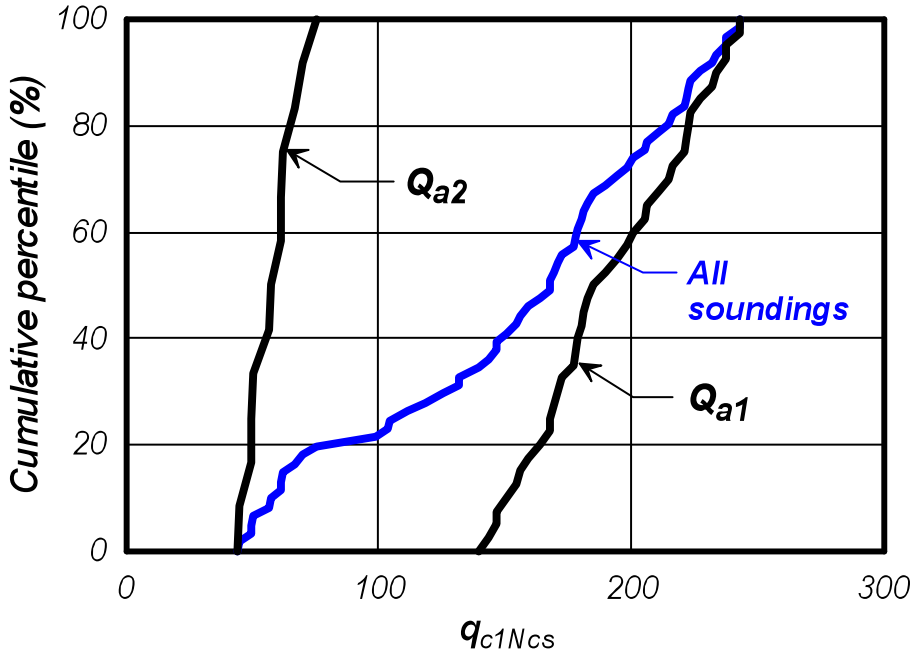




Lateral spreading requires some continuity of liquefied layers, whereas settlement does not.

Representative values for "homogenous" units

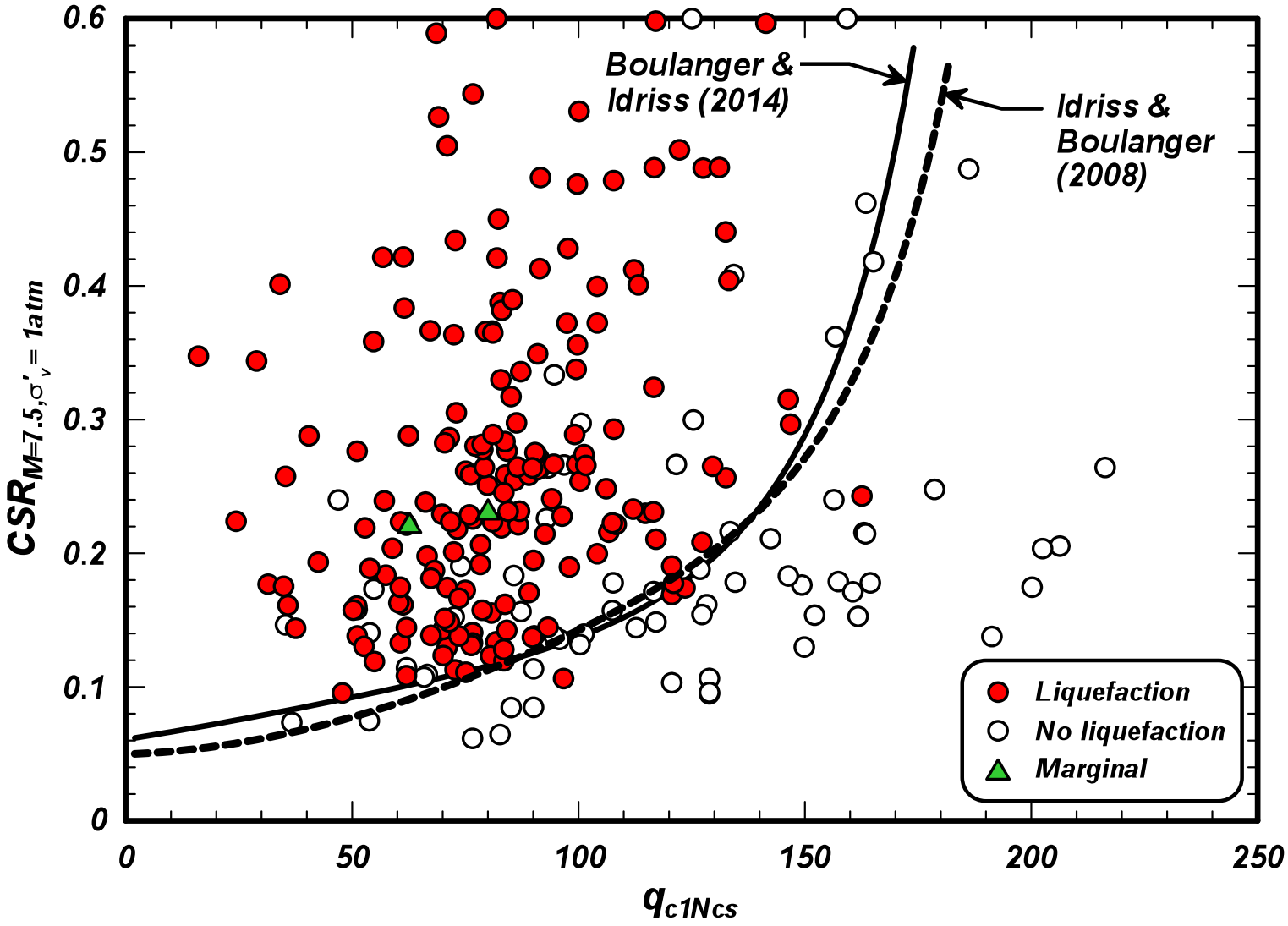




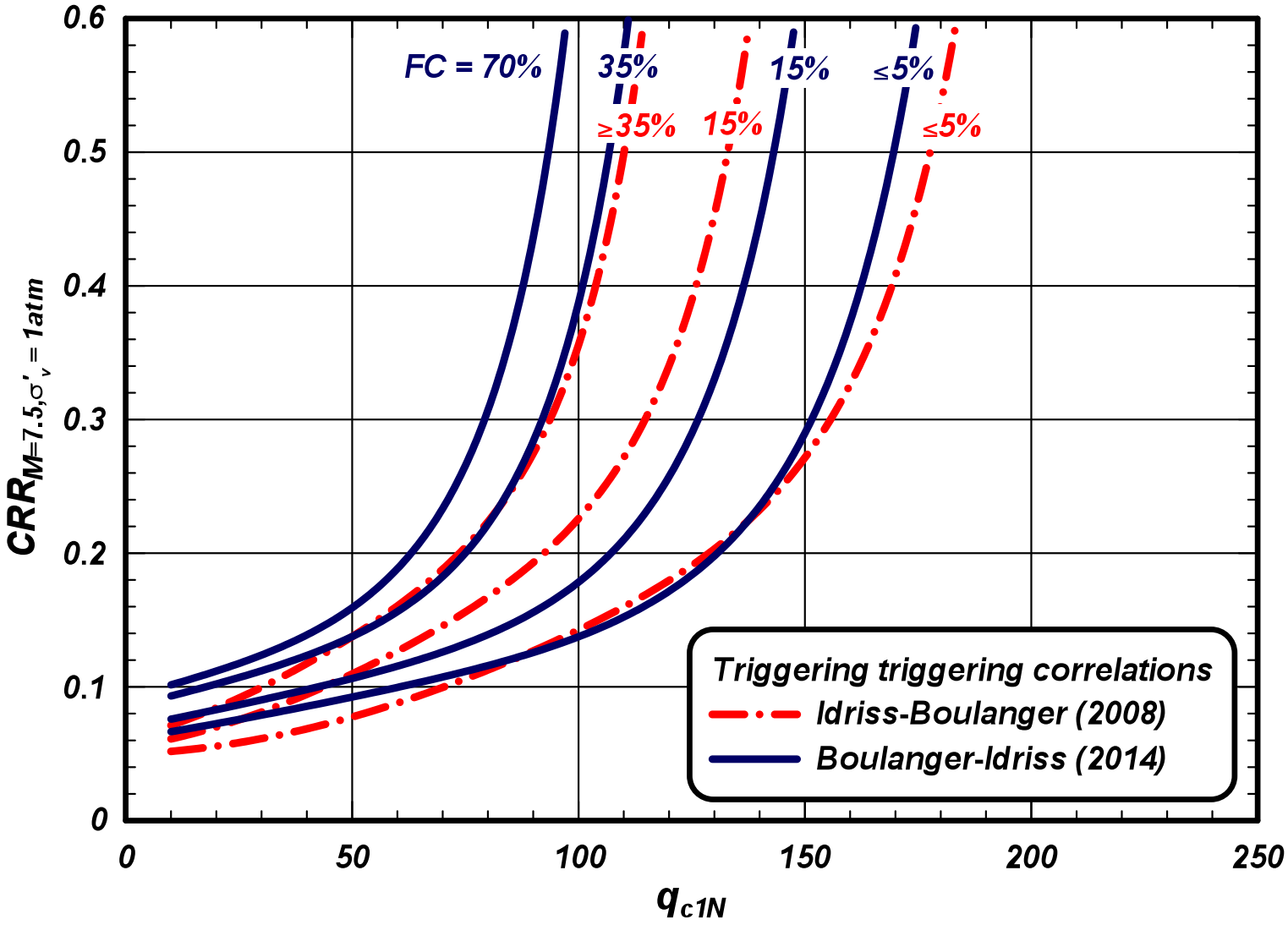
Look for continuity in looser layers. Do the geologic conditions suggest continuous zones are likely?

In-situ testing:
Example of calibration

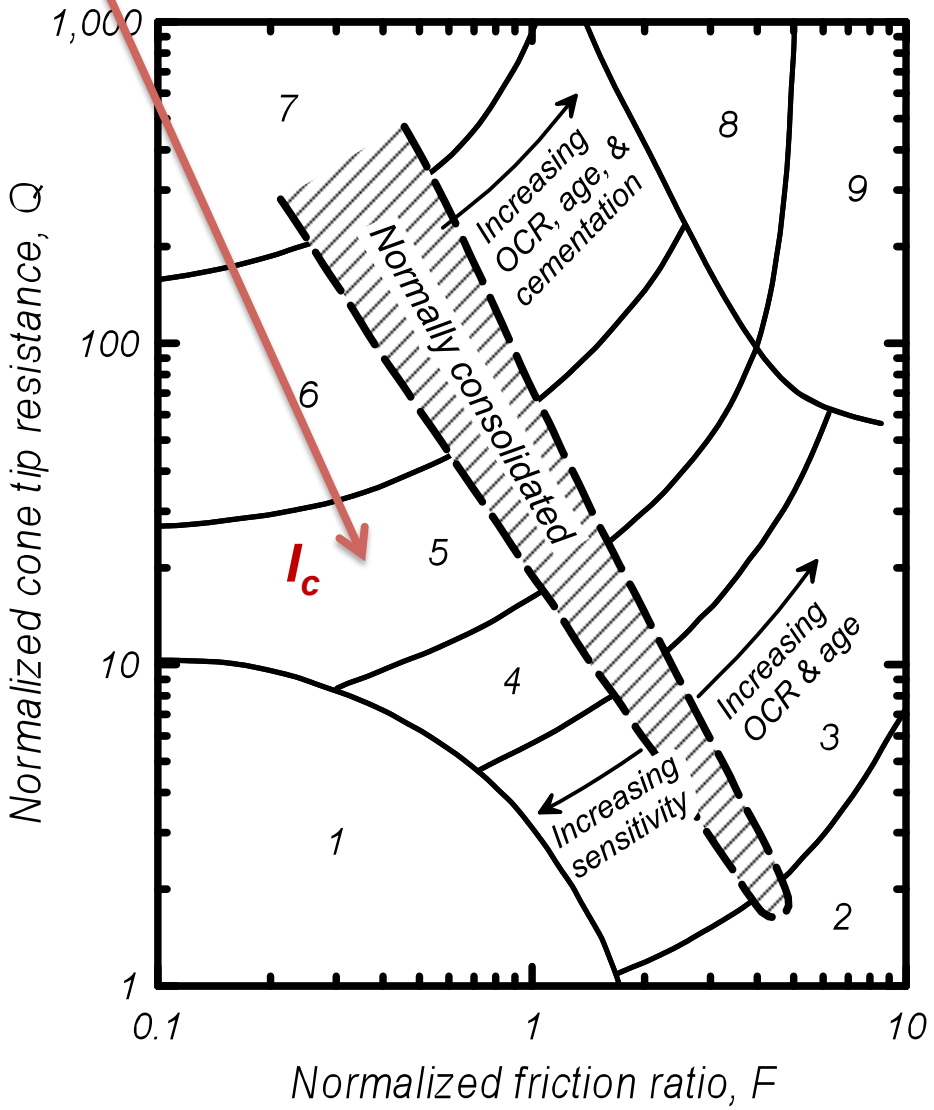
CPT-based triggering correlations



CPT-based triggering correlations



Soil behavior types

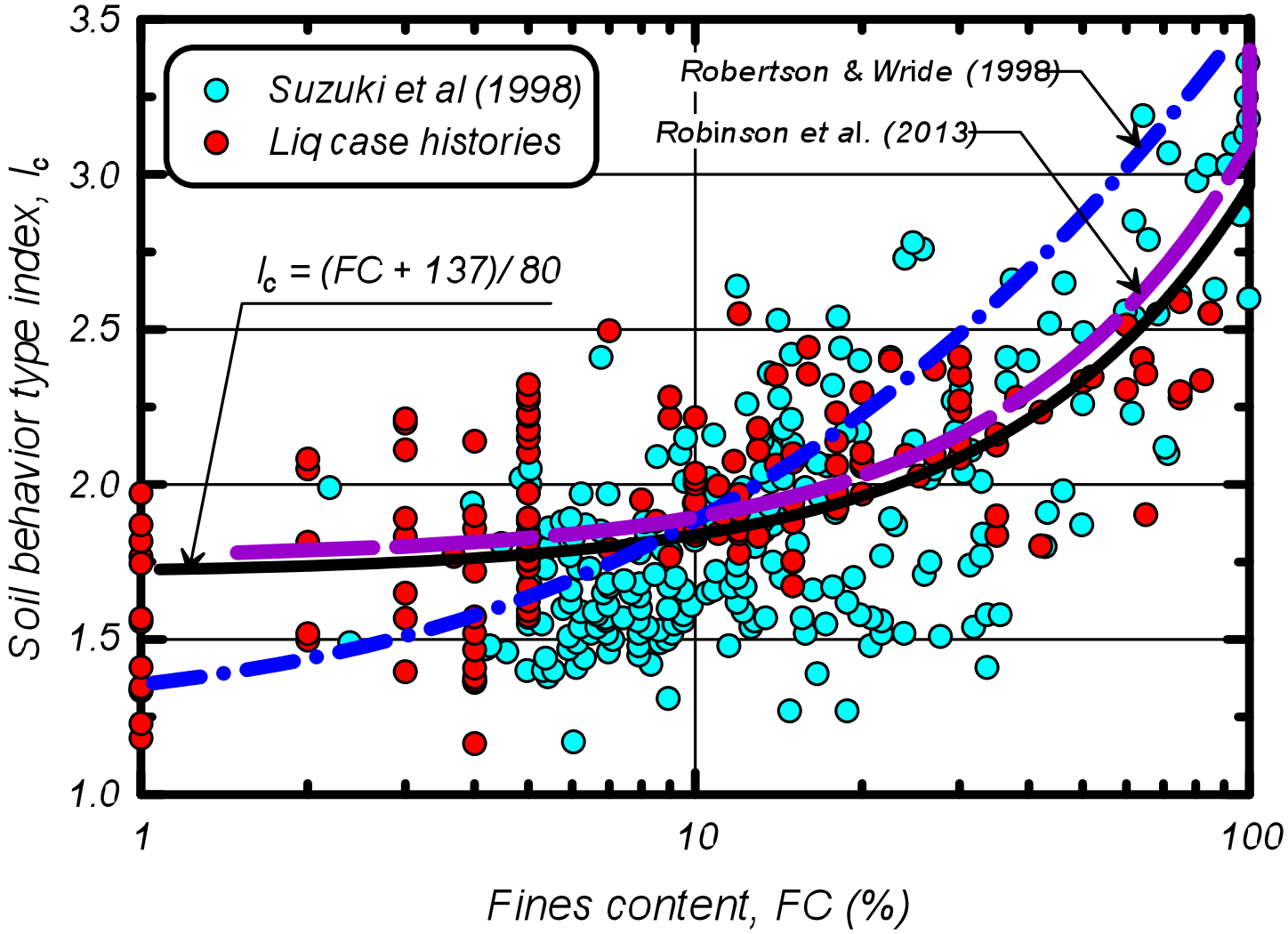


1. Sensitive, fine grained
2. Organic soils - peats
3. Clays - silty clay to clay
4. Silt mixtures - clayey silt to silty clay
5. Sand mixtures - silty sand to sandy silt
6. Sands - clean sand to silty sand
7. Gravelly sand to dense sand
8. Very stiff sand to clayey sand *
9. Very stiff, fine grained *

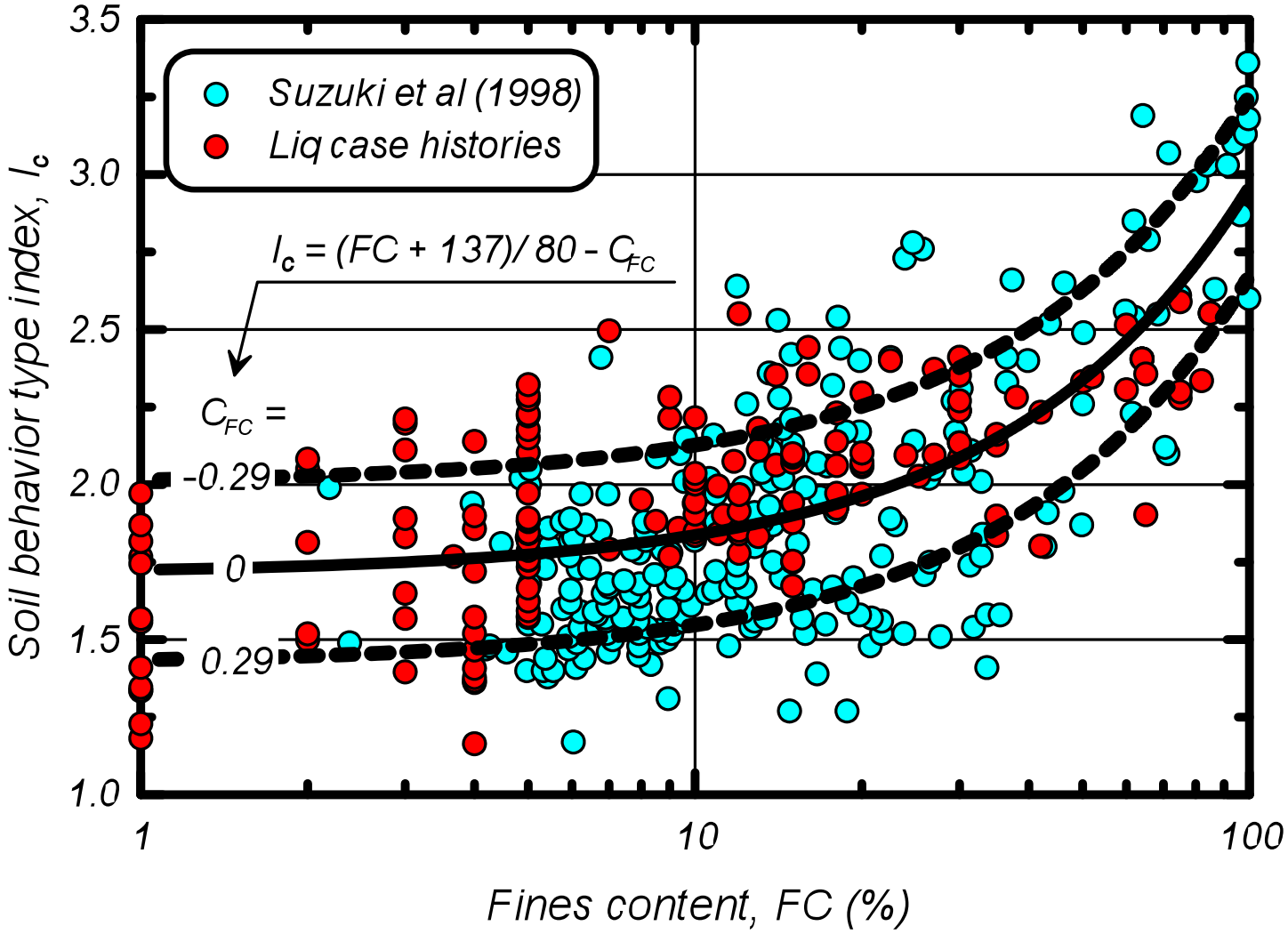
I_c = radial distance from reference center pt.

Robertson (1990)

FC from CPT data

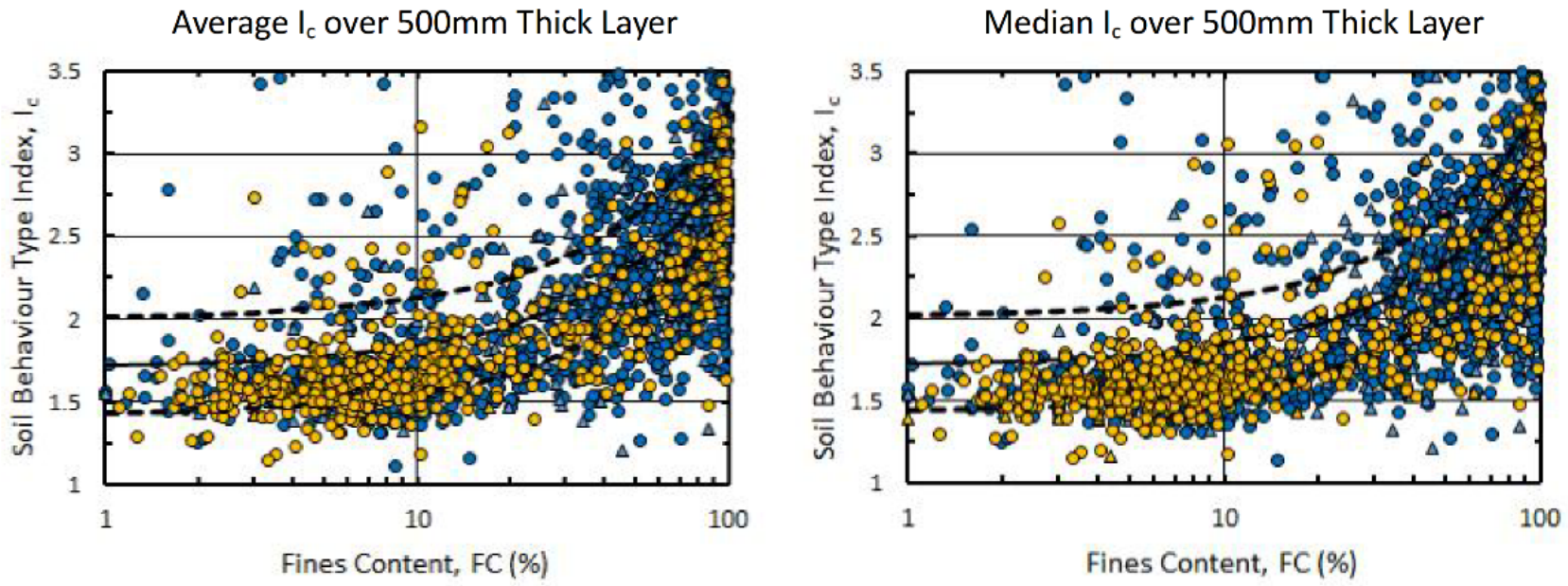


FC from CPT data



FC from CPT data

- ***Christchurch regional correlation: C_{FC} ≈ 0.2 (Van Ballegooy et al. 2015; Tonkin and Taylor 2014)***



Estimating FC & soil type

- *Can develop site-specific and region-specific correlations for C_{FC} and/or the I_c cutoff value used for identifying clay-like soils.*

- *If site-specific sampling and index test data are not available*
  - *Check sensitivity to uncertainty in C_{FC} (e.g., -0.29, 0, and 0.29 for no site-specific or region-specific information).*

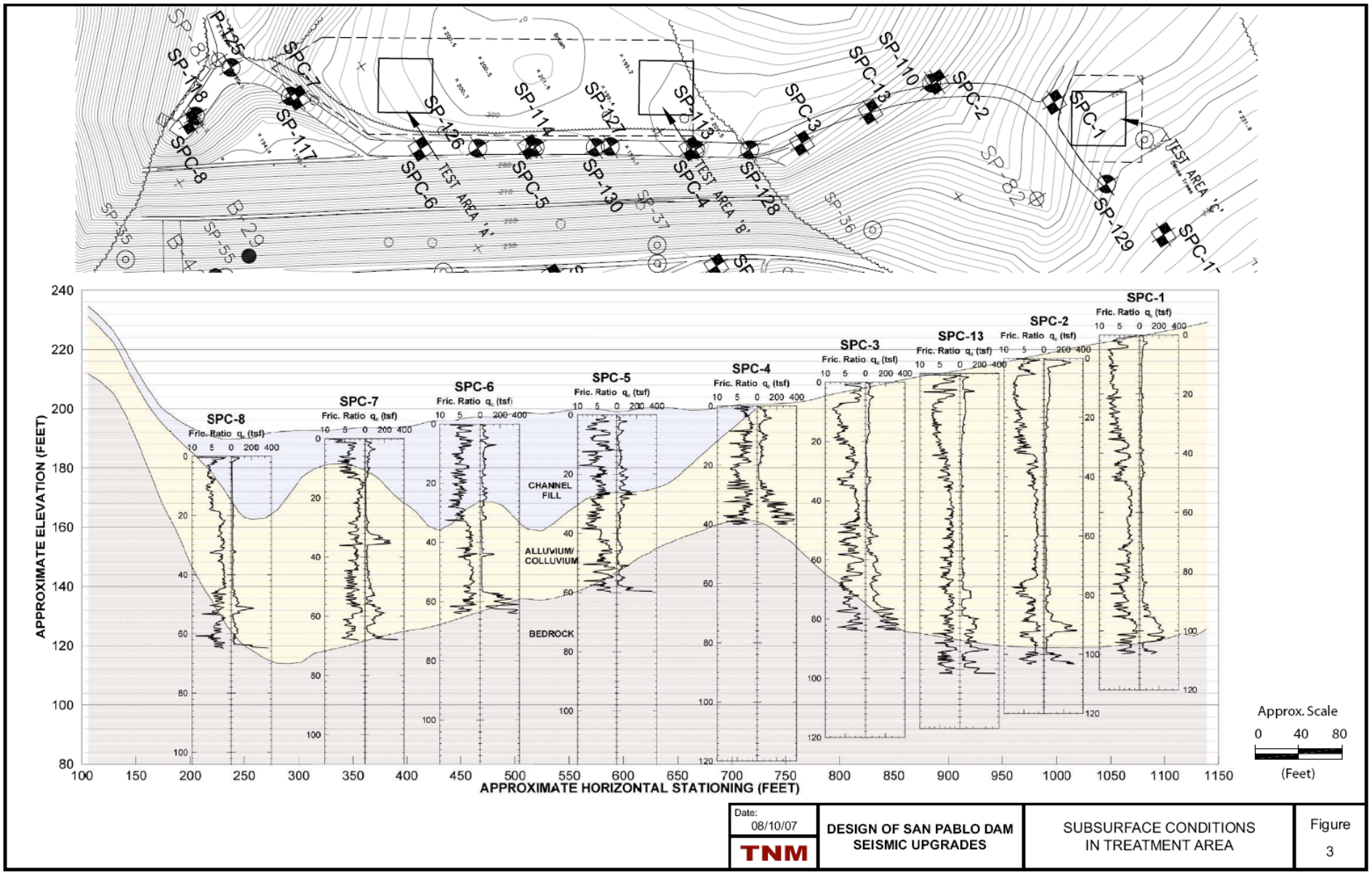
$$FC = 80\left(I_C + C_{FC}\right) - 137$$

  - *Similarly check sensitivity to the I_c = 2.6 value commonly used to identify clay-like soils; e.g., I_c = 2.4, 2.6, 2.8*

- *Note that the calibration of C_{FC} can be adjusted for before/after ground improvement to ensure that the estimated FC remain consistent with the lab data. Similar site-specific adjustments in CLiq program as described in Nguyen et al. (2014).*

Remediation alternatives:
Example of constructability issues

Remediation at San Pablo Dam by EBMUD (2007-2009)



Graphic courtesy TNM joint venture (2007)

Test sections in 2007: One challenge was the interface between the panels and bedrock

Test sections in 2007: One challenge was the interface between the panels and bedrock

Photo courtesy EBMUD

Production work in 2009:

- *Geologic properties at test sections turned out to be atypical, so they had to remobilize to characterize and define bedrock depths*
- *Final choice - deep soil mixing with pre-drilling to key into bedrock*

Concluding remarks

Concluding remarks

- ***The geologic data needs for engineering mitigation of liquefaction hazards depend on the engineering system***
- ***The geotechnical data needs for engineering mitigation of liquefaction hazards depend on the geology***
- ***Primary need is almost always clear technically-informed communication between geologic and geotechnical personnel***

Questions?

UC DAVIS
UNIVERSITY OF CALIFORNIA

Ross W. Boulanger
Professor

REVIEWING FAULT SURFACE-RUPTURE AND EARTHQUAKE-HAZARD-MITIGATION REPORTS FOR REGULATORY COMPLIANCE

Robert A. Larson
Charles Nestle Los Angeles County Department of Public Works, 900 S. Fremont Avenue, Alhambra, California 91803
rlarson@dpw.lacounty.gov; cnestle@dpw.lacounty.gov

Regulatory review is an evaluation of the technical content, conclusions, and recommendations presented in a report, in relation to the geology of the site and the proposed project. This practice is completed by professional (hopefully licensed) geologists and engineers. This is different than ministerial review that only determines that a report has been completed and submitted for the job, but does not require review of the technical content.

For regulatory review to work as a protection for the public, you need supportive politicians and bureaucrats, laws and regulations (building\grading codes), policies, and experienced professionals who understand the review process. The professionals may be consultants or work directly for the regulating government agency or another government agency. In Los Angeles County, the Los Angeles County Department of Public Works (LACDPW) has an extensive set of policies developed since 1960, as well as a 95-page guideline to inform consultants of what is expected in a geologic-hazards investigation report. Specific geologic conclusions are required by regulation prior to approval of a project. Disputes between reviewer and consultant may arise that require a dispute or appeals board. Los Angeles County has a rarely used an appeals board, but when necessary, the members are chosen from political districts and may not have the necessary expertize for this type of work. Similarly, other jurisdictions have set up a one-time review board for a specific project.

Earthquake-hazard-mitigation reports are pretty standard now, and required by the building code. Black box numbers can be obtained at United States Geological Survey and California Department of Transportation websites for ground-motion estimates. The numbers, material properties of soils, and groundwater data can be inputted to programs to determine liquefaction potential. Landslide analysis is standard practice, and usually evaluated statically and pseudostatically, and only occasionally by the displacement method. Regulatory reviewers need access to and the ability to use these programs.

Fault surface-rupture investigations require the use of professional judgment much more than earthquake-hazard evaluation. Construction and logging of trenches across fault zones is expensive, technically challenging, and subject to safety regulations. Hopefully, the reviewing geologist will be invited by the consultant to observe open trenches and the logging technique. Problems develop when insufficient data are presented by the consultant, either though poor practice or geologic conditions. When soils of a suitable age are not present, but a fault is, the property may not be developable for residential or commercial structures. When young soils are too thick to evaluate the possible presence of a hazardous fault, there may be insufficient room on the property or insufficient budget to complete a trench. Determining the age of the soil can be a problem for reviewers. When datable materials are not present, and techniques that require extensive professional experience to use are required, the LACDPW has relied on a very small pool of practitioners that have a publication/presentation record of soil dating. Now, the next generation of practitioners is coming on board and trust issues are developing.

Case histories will be presented that demonstrate incompetent practice in siting a trench, insufficient data, and insufficient trench depth.

The opinions expressed are solely those of the author, and do not represent the opinions of, nor endorsement by, the LACDPW.

The following is a PDF version of the author's PowerPoint presentation.

REVIEWING FAULT SURFACE-RUPTURE AND EARTHQUAKE-HAZARD-MITIGATION REPORTS FOR REGULATORY COMPLIANCE

Robert A. Larson
Charles Nestle
Los Angeles County
Department of Public Works

Regulatory review is an evaluation of the technical content, conclusions, and recommendations presented in a report, in relation to the geology of the site and the proposed project to determine compliance with regulations. Both consultants and reviewers should be licensed.

Ministerial review is accepting the report, signed by a licensed professional, without looking at the technical content. Case history will show problem with this practice. This is still common practice in many areas of California

Goal: protection of the health, safety, and welfare of the public. A developer is the public, but is only owed a diligent review, not protection of their welfare

L A County reviews for residential/commercial development – State of California reviews hospital and school sites

WHY SHOULD UTAH ADOPT THIS PRACTICE???

To stop building legacy projects that are subject to geologic hazards. We have the knowledge and ability to identify and mitigate hazards.

WHAT DO YOU NEED TO SET UP A REGULATORY REVIEW SYSTEM:

Politicians and agency administrators that support the concept.

Why should they? Draper City 400K/year in litigation costs could be spent on other endeavors that promote their careers

Building\grading codes and other regulations that include appropriate language

2012 International Building Code; Modified by State of California; Then modified by Los Angeles County

Policies

Policy Memos are at http://interdev/gmed/permits/index.cfm?p=memos

Experienced professionals to perform the review process, either agency personnel or private consultants

Licensed professional geologist or engineer

What does this mean?

Person has demonstrated minimal competence in field

Allowed to practice in State

That's it!!!!!

Record keeping – go electronic

3
5
MT
PD
DS

2014 COUNTY OF LOS ANGELES BUILDING CODE

Effective January 1, 2014

SECTION 110
PROHIBITED USES OF BUILDING SITES
Section 110.2 Geotechnical Hazards

No building or grading permit shall be issued……when the Building Official finds…… This is the justification for review

SECTION 111
ENGINEERING GEOLOGY AND SOILS ENGINEERING REPORTS

The Building Official may require an engineering geology or soils engineering report, or both, where in the Building Official's opinion, such reports are essential for the evaluation of the safety of the site. *The ….report….shall contain a finding regarding the safety of the site of the proposed work against hazard from landslide, settlement or slippage and a finding regarding the effect that the proposed building or grading construction will have on the geotechnical stability of the area outside of the proposed work.*

SECTION 113
EARTHQUAKE FAULTS

SEISMIC HAZARDS

Ground motion

Black box for small projects

Landslides

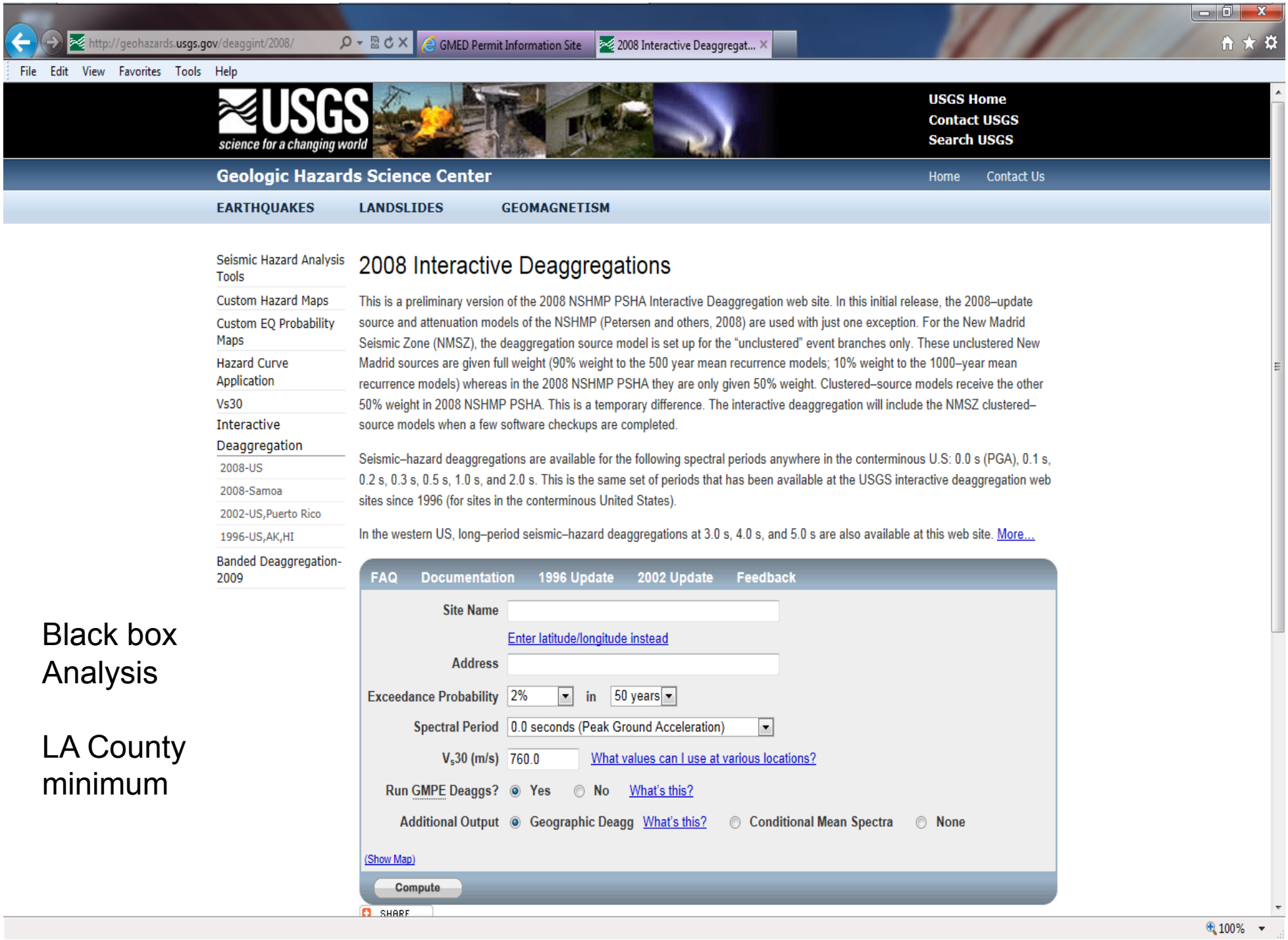
Well understood by most
Psedostatic accepted, Newmark deformational analysis not accepted

Liquefaction

L.A. County 2009 Liquefaction Letter To Consultant
13 MOST COMMON PROBLEMS WITH ANALYSIS
http://interdev/gmed/permits/docs/LiquefactionHazardAssessment.pdf

Seismic Hazard Mapping Act

Maps not really useful to review, but the data reports for each quad are great and used daily



Black box Analysis

LA County minimum

FAULT SURFACE RUPTURE

Active Fault Defined in LA County Building Code

Therefore, Los Angeles County considers a fault active if it has displaced Holocene materials, and requires a fault investigation to penetrate the Holocene-Pleistocene boundary. All fault investigation excavations must extend through the Holocene and into Pleistocene deposits in order to demonstrate the lack of Holocene fault activity. If appropriate data cannot be provided, then the presence of an active fault trace within the area of investigation must be assumed.

AP Earthquake Zone Maps used, but also LA County Seismic Safety Element (San Gabriel fault), and 1991 Sierra Madre EQ (Sierra Madre Fault which is not AP zoned)

BIGGEST PROBLEMS FOR LA COUNTY

Determining the Holocene-Pleistocene boundary

After AP zones defined, County Engineer tired of augments over depth, so regulation established to limit exploration to 5 feet. Regulation rescinded many years ago.

Other problems

Poor logs

Failure to clean walls

Fault versus crack

Lack of space for trench

Lack of suitable soils for dating

CASE HISTORIES

Regulatory review at work

Lack of analysis

Trench orientation parallel to fault

Insufficient depth

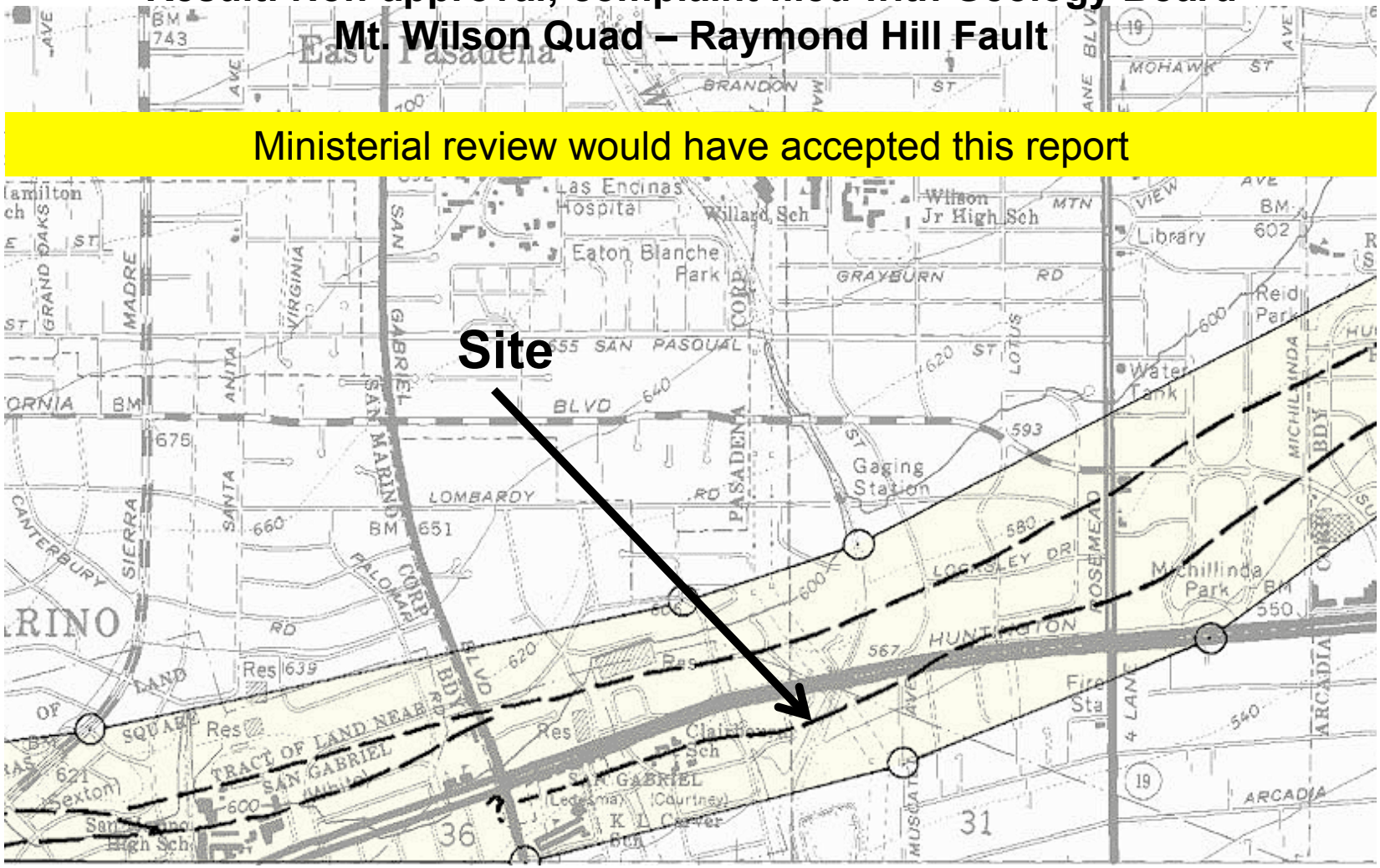
2 PAGE REPORT - SURFACE OBSERVATIONS ONLY – TRIED 50 FOOT RULE
CONCLUDED HAZARD MINIMAL

Sunnyslope Drive, San Gabriel

Result: Non-approval; complaint filed with Geology Board

Mt. Wilson Quad – Raymond Hill Fault

Ministerial review would have accepted this report

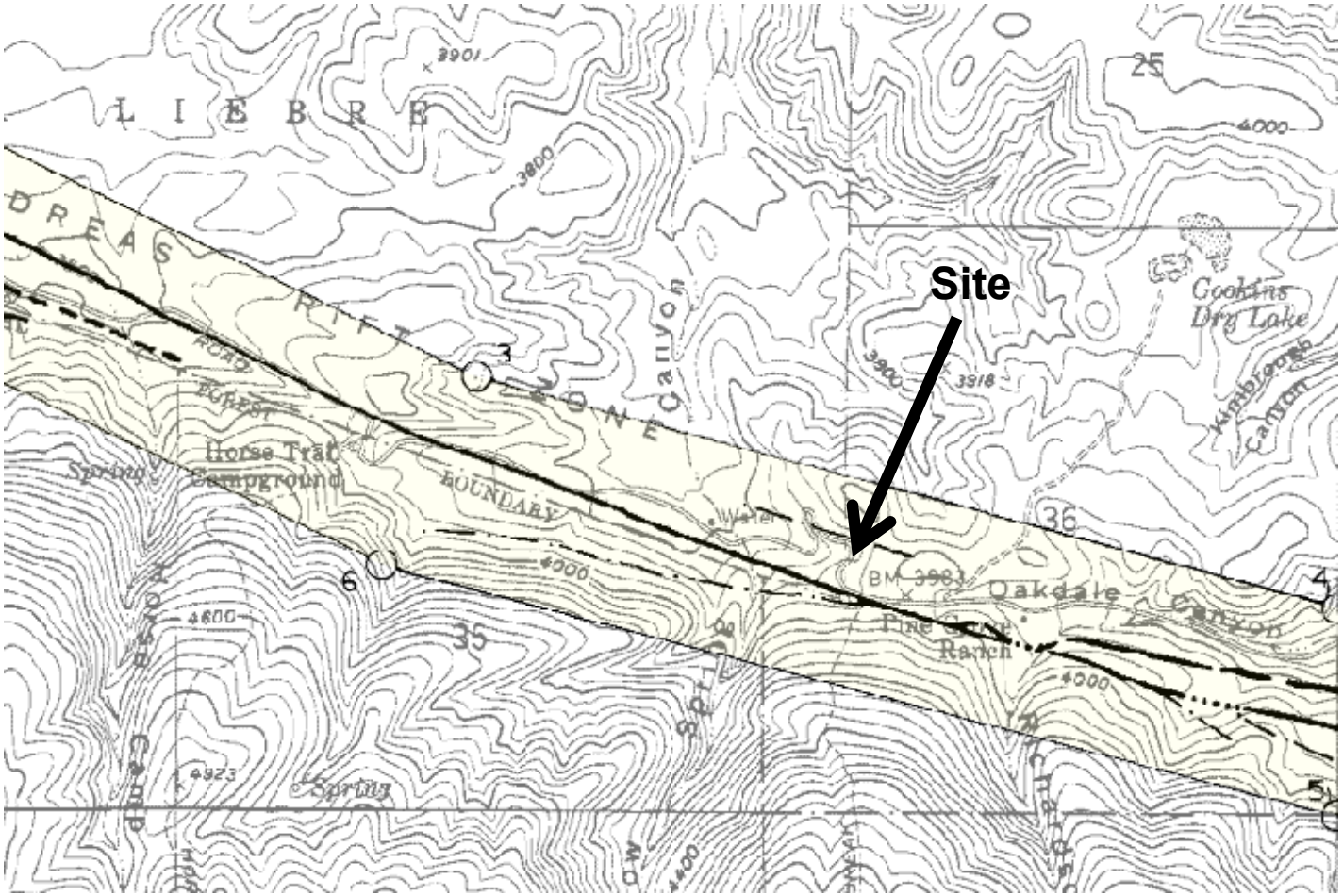


TRENCH PARALLEL TO FAULT

28963 Pine Canyon Road

Result: Citation by Geology Board

Liebre Mtn. Quad – San Andreas Fault



INSUFFICIENT DEPTH OF EXPLORATION – DID NOT FIND FAULT

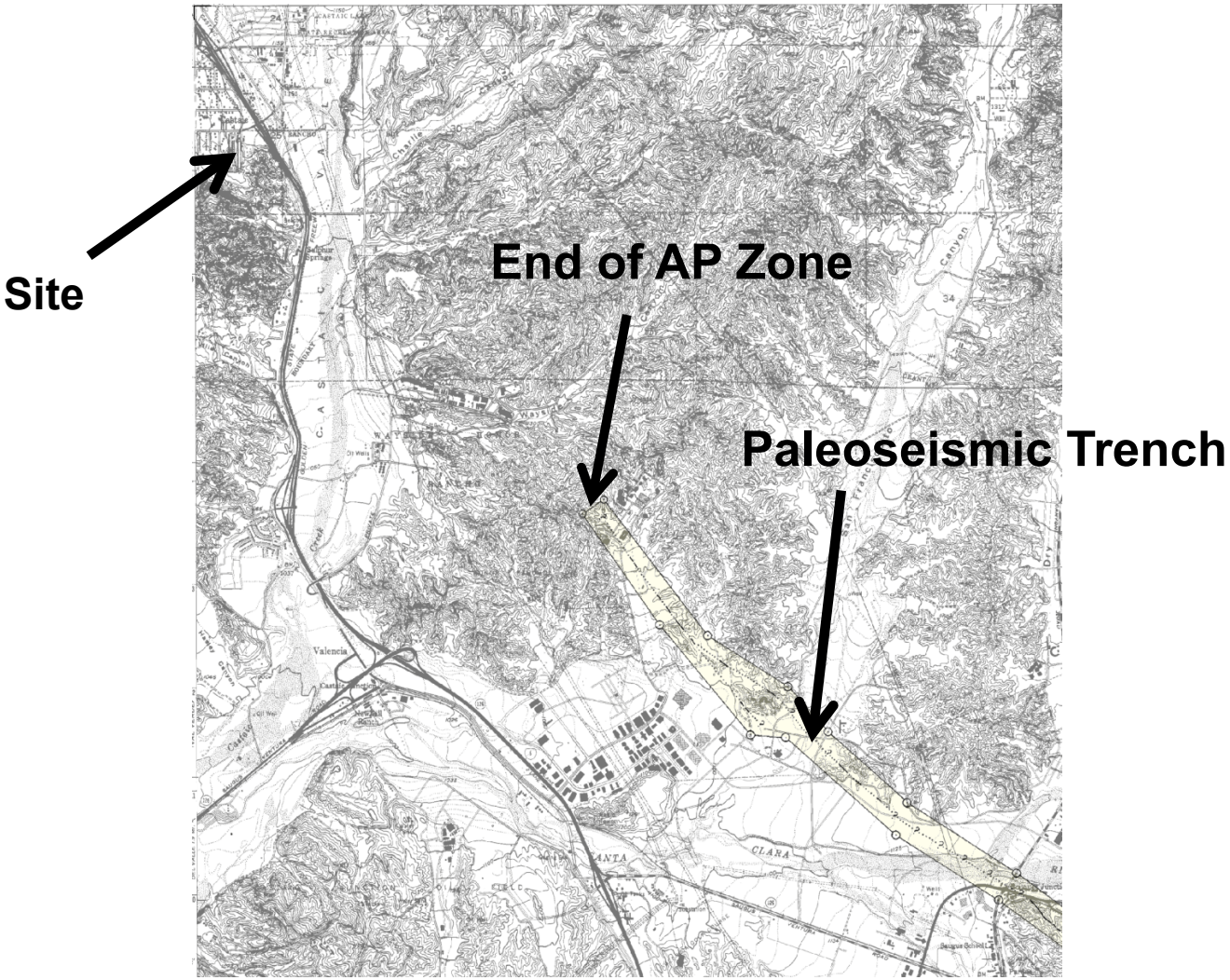
Tentative Tract 47646

Result: New consultant found fault at depth

Redesign of tentative tract and grading plan at great expense

Newhall Quad – San Gabriel Fault

Basis for activity: LA County Seismic Safety Element



Faults cross roads with utilities
Infrastructure affected if surface rupture occurs

Comments

Reviewers do not need to agree with interpretations in order to approve the project

Reviewers need to be thick skinned because their professionalism will be challenged

Draper City wanted uniform standards and uniform results, but…..
Just like different consultants will produce different reports, different reviewers will ask different questions

Draper City 2006 Revised Hazard Ordinance
Avoidance is best – great
But mitigation increases area of land use

Utah is a property rights state, so if City approves project, the City accepts liability (tax payers pay for developers mistakes)

Big Rock Mesa litigation
Upon appeal, California Superior Court determined jurisdictions do not have liability for issuance of building/grading permits – it just a function of government

ADVOCACY

Implementation of regulations and regulatory review can help eliminate or at least greatly reduce the damage from geologic hazards

So why wait????
Eliminate legacy projects now
Save the expense of infrastructure repair

The builder/developer pays for the loss, not the tax payers.

WHERE TO GET LA COUNTY REGULATORY INFORMATION

MANUAL FOR PREPARATION OF GEOTECHNICAL REPORTS
163 pages with multiple guidelines
http://interdev/gmed/permits/docs/manual.pdf

SEISMIC VULNERABILITIES OF NATURAL GAS SYSTEMS

Peter W. McDonough, P.E., F. ASCE
Senior Engineer, Questar Corporation
1140 West 200 South, Salt Lake City, Utah 84145-0360
pete.mcdonough@questar.com

OVERVIEW

Natural gas is used extensively throughout the industrialized world. Within the United States, approximately 25% of all energy consumed is produced from natural gas. 67 million homes, 5 million businesses, 190,000 factories, and 1900 electric generating facilities rely on natural gas, according to the American Gas Association (AGA), a leading trade organization (AGA, 2014).

Gas product is transported through 2.4 million miles (3.9 million km) of pipeline of various sizes and pressures. These pipelines crisscross all sections of the country, emanating from gas producing areas, and fan out into distribution grids that serve most urban and suburban regions of the nation.

While welded steel is used for pressures above approximately 60 pounds per square inch (41 N/cm^2), at lower pressures polyethylene plastic is often utilized. Older gas distribution systems may also contain cast or ductile iron pipes, although these materials are no longer being installed. Additionally, at lower pressures, steel pipe may be joined by compression couplings, rather than butt welds.

Although natural gas pipelines and facilities are typically very robust and are designed with significant factors of safety, there are seismic vulnerabilities and risk inherent to any built facility that gas system owners and operators need to acknowledge and plan for.

SHAKING EFFECTS ON PIPELINE FACILITIES

While one might anticipate pipe failure at points of ground displacement, as would be caused by fault movement or liquefaction, the most widespread system damage (which may include equipment and customer appliance damage) will likely occur due to ground shaking.

Observations have shown that ground shaking parameters, such as ground acceleration and velocity, directly correspond to what below ground piping experiences, and thus it can be said that, in most situations, below ground piping mirrors the soil response to the seismic event.

In American Society of Civil Engineers (ASCE) monograph Seismic Design Guide for Natural Gas Distributors (ASCE, 1995) natural gas facility response was compared to Modified Mercalli Intensities (MMI). Converting MMI to peak ground acceleration (PGA) using the equation:

$$MMI = 3.66 \log (PGA) - 1.66 \quad \text{(Wald, 1999)}$$

provides the following guidelines of what types of damage might be expected:

- At a PGA of approximately 0.12g (118 cm/sec^2) (MMI=VI) one might expect the onset of metering or appliance damage, particularly in mobile homes.

- At a PGA of 0.23g (226 cm/sec^2) (MMI=VII) cast iron pipe damage may occur, particularly in smaller pipe sizes with constrained joints. Metering and appliance damage in permanent structures occurs.

- At a PGA of 0.44g (432 cm/sec^2) (MMI=VIII) significant cast iron damage can be expected. Failures of old or uncoated steel pipelines occur. Polyethylene pipe damage occurs at stress concentrators such as service connections.

- At a PGA of 0.82g (801 cm/sec^2) (MMI=IX) there is probable damage to steel piping systems. Structural damage to buildings will further damage above ground metering and other ancillary equipment.

- At a PGA of 1.5g (1471 cm/sec^2) (MMI=X) one can expect significant damage to steel piping systems.

A second observation is that changes in seismic wave characteristics, such as might be expected as the wave travels between different types or densities of soil, may initiate shear stresses in a pipeline that bisects these soils. While this normally will be a secondary concern, in certain situations such as the boundary between liquefiable and non-liquefiable soils, physical shear of the soil mass can compromise the pipeline.

Below ground piping is most vulnerable at expected points of weakness. These might include:

- Obvious stress concentrators such as elbows, valves, and locations where pipe diameter or wall thickness changes.

- Bell and spigot joints on old cast iron pipe systems. Note that this type of joining method is still common on water and sewer pipelines, but is no longer used on new natural gas pipes.

- Compression couplings. These are still used on lower pressure gas distribution systems.

- Areas subject to corrosion.

- Oxyacetylene welds, which were common before 1940 on steel manufactured natural gas pipelines.

Above ground piping facilities, such as metering stations, compressors, and tankage behave as structures during ground shaking. They can be analyzed and should be designed as such, using guidance provided in applicable codes. Specific damage effects might include:

- "Elephant foot" buckling at the base of large liquefied natural gas tanks. This is a relatively common event on oil and water tanks, caused by the sloshing of the liquid in the tank due to the ground motion. Many tanks are not designed for the uneven horizontal force that occurs, with the resulting buckling of the steel tank.

- Overturning or pipe connection failure at compressed natural gas, propane, and vertical liquefied natural gas tanks. Compressed natural gas and propane tanks are typically on legs of various lengths. Unless seismic effects are taken into account in their design, they typically are not bolted to a foundation and are subject to sliding or overturning. Tall, vertical liquefied natural gas tanks are sometimes installed at commercial fueling stations that sell this product for vehicle fuel. If not properly anchored, these could fail with very serious implications.

- Catastrophic failure of old low pressure water or tar seal gas holders. These may be subject to cap tilting or structural member failure. Fortunately, there are few of these left in the United States. Those that are likely are over seventy years old, and pose a serious risk during an earthquake.

- Metering facility damage caused by oscillating movement of heavy meter or filter components attached to flanges or relatively thin walled piping. Metering facilities adjacent to buildings might also be damaged by falling masonry or other building elements.

- Piping that is attached to a building with rigid connectors will likely mirror the building's response to the earthquake. Pipe stresses can be calculated based on the building's dynamic motions and elastic or plastic deformations predicted.

LIQUEFACTION EFFECTS ON PIPELINES

Liquefaction poses a definite risk to pipelines, resulting in increased pipe stress, primarily due to buoyancy effects. Lateral spreading may cause excessive shear stress at the boundaries of the spread, similar to faulting. If movement is significant on slopes as slight as 3 to 5 degrees, the soil failure replicates a landslide, which places significantly more stress on the pipeline.

Loose, low cohesion fills at waterfronts, alluvial fans, active flood plains, and river channels are particularly susceptible to liquefaction and subsequent failure of pipelines that traverse them.

The most significant U.S. example of liquefaction damage to natural gas piping occurred during the 1989 Loma Prieta earthquake (**M** 7.1, MMI=IX). In the San Francisco Marina District, the entire cast iron gas distribution system had to be replaced due to severe liquefaction damage. However, this was bell and spigot jointed, rigid pipe and not the ductile welded or plastic fused pipe that is currently installed.

Typical mitigation practice would be to consider using heavy wall, concrete coated or "weighted" welded steel pipes in liquefaction susceptible areas. Additionally, stress concentrators, as described above, should be minimized, as well as the use of couplings. If liquefaction area boundaries can be accurately identified, fault design techniques and mitigation can be used.

LANDSLIDE EFFECTS ON PIPELINES

Landslide risk can range from inconsequential to catastrophic to pipelines. Rockfalls are typically surface events and as such, pose minimal risk to buried pipelines and valves, although they can damage or destroy above ground facilities.

If the locations of possible shallow slides or slumps are known, shallow pipe depth in combination with an engineered, low cohesion backfill (such as sand) may permit the pipe to break free of a future slide. That, in conjunction with few stress concentrators near the shear boundaries significantly improves the probability of maintaining pipeline integrity.

Deep translational and rotational slides pose a significant risk, with the only practical mitigation being avoidance of potential sites, long-term monitoring, or installing isolation valves in the near vicinity.

FAULT EFFECTS ON PIPELINES

Pipelines must deform longitudinally and in flexure to accommodate fault movement, with effects caused by strike-slip and reverse faulting much more difficult to mitigate than normal faulting. Closely spaced parallel faults or splays, antithetic faulting, and graben formation during normal faulting events increase the risk of pipe failure.

A key to minimizing risk at fault crossings is to carefully design the pipe with regard to strength and wall thickness. Care in trench design, with particular regard to backfill material, trench shape, and pipe burial depth; as well as minimizing stress concentrators will reduce stress on the pipeline. It is possible to design for several feet of vertical fault movement, assuming the pipe can safely break free of the soil above it on the downthrown side of the fault.

SEVERAL EXAMPLES

Several examples help illustrate how earthquakes have damaged natural gas pipeline infrastructure. During the 1971 San Fernando earthquake (**M** 6.6, MMI= X), there were 456 reported failures to the natural gas system. Damage occurred within a 12 square mile (31 square kilometers) area, which caused 16,300 customers to lose gas service. It took eleven days to restore service. Pipe age and welding technique were contributing factors to the damages.

During the 1989 Loma Prieta earthquake (**M** 7.1, MMI=IX), approximately 1000 natural gas leaks were reported. 156,000 customers were without gas service (although many had turned off their gas service unnecessarily, due to fear of possible leakage). It took ten days to restore service to all areas except the San Francisco Marina District, where the entire cast iron gas distribution system had to be replaced due to severe liquefaction damage. Steel and polyethylene plastic pipe were also impacted, and pipeline corrosion, which caused the pipe to have less wall thickness and subsequent strength, caused a substantial number of failures.

During the 1994 Northridge earthquake (**M** 6.7, MMI=X), 669 pipe leaks were reported. 150,800 customers were impacted (however, as with the Loma Prieta event, a number of customers had turned off their gas service unnecessarily). The major-

ity had service back within twelve days. Damages occurred on welded steel pipe and polyethylene plastic pipe. Age and pipe corrosion both played roles in increasing the number of failures.

OPERATIONAL VULNERABILITIES

While failure of the physical infrastructure is the topic most often discussed regarding natural gas system vulnerability, maintaining functionality also relies on numerous operational issues.

- Telemetering and communications systems, critical in controlling long distance gas supply and flow, may be compromised due to power loss at office locations.
- The emergency response to gas leaks may be compromised due to bridge or road failure and closure.
- Damage to adjacent (or "co-located") infrastructure, such as water mains or high voltage power lines may impact gas pipelines or the ability to reach them.
- Office operations, including management functions may be seriously compromised by office building damage. Even minor building damage, such as the failure of suspended ceilings, toppling of computers and file cabinets, and water damage due to damaged fire suppression systems will effect operations to varying degrees.

MITIGATION

The first step in reducing system vulnerability, both at a corporate and individual level, is the most logical: acknowledgement of the underlying hazard and subsequent risks. It is very easy to put aside concern for low probability, yet high consequence events in the face of the near term challenges that must be addressed in the business world. Yet for any organization to begin addressing seismic vulnerability, it must make the commitment and take the time to study the issue. In the case of a natural gas provider, regional as well as local risk must be addressed.

Natural gas production areas and supply pipelines may be many miles from the eventual usage area. The seismic hazard throughout the region must be considered, since flow interruption can occur anywhere along the supply corridor. Similarly, the local hazard, which causes the various risks described in this paper, has to be totally understood.

The next step in mitigation is assessing individual system component vulnerabilities. This can be a very labor intensive process, but is another critical step in reducing risk. Different types of pipe materials have varying shear and tensile strengths, and will be subject to different degrees of shaking intensity depending on soil type and distance from the seismic source. Above ground facilities may be located within structures that may or may not be able to withstand ground shaking.

Combining the individual component vulnerabilities leads to the modeling of the total system. This will include predicting the number of pipe failures and product loss, as well as resultant system pressures. An additional component is predicting the number and types of failures of customer equipment as well as estimating structural failures that would also likely damage gas fired equipment.

Once appropriate studies are completed, either on a deterministic or probabilistic basis, immediate retrofits or changes to design practices can be evaluated. These goals have to be realistic, taking into account cost/benefit analysis.

Oftentimes, these studies can lead to improved employee and customer training in seismic issues, as well as provide topics for management and operations employee table top exercises of the emergency plan.

REFERENCES

American Gas Association, 2014, Facts about natural gas: online, www.aga.org.

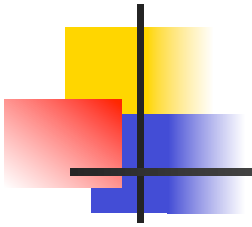
McDonough, P.W., editor, 1995, Seismic design guide for natural gas distributors: American Society of Civil Engineers, TCLEE Monograph No. 9, p. 87-88.

Wald, D., Quitoriano, V., Heaton, T., and Kanamori, H., 1999, Relationships between peak ground acceleration, peak ground velocity and Modified Mercalli Intensity in California: Earthquake Spectra, v. 15, no. 3, p 558.

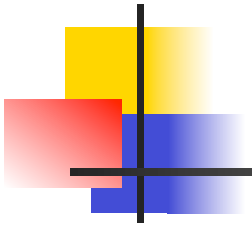
The following is a PDF version of the author's PowerPoint presentation.

SEISMIC VULNERABILITIES OF NATURAL GAS SYSTEMS

Peter W. McDonough P.E., F. ASCE
Chairman- American Society of Civil Eng., Technical Council of Lifeline Earthquake Engineering, Gas & Liquid Fuels Committee
Senior Engineer- Questar Corporation, Salt Lake City, UT

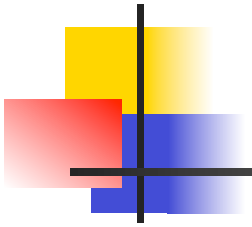


VULNERABILITIES DEFINED BY HOW THE GEOLOGIC EFFECTS OF THE SEISMIC EVENT INTERACT WITH THE PHYSCIAL PROPERTIES OF THE PIPING SYSTEM & IMPACT SAFE OPERATIONS



EARTHQUAKE SHAKING EFFECTS

- BELOW GROUND PIPING MIRRORS SOIL RESPONSE
- ABRUPT CHANGES IN SOIL TYPE INITIATE PIPE SHEAR STRESSES
- FREE STANDING ABOVE GROUND PIPING BEHAVES AS A STRUCTURE
- PIPE ATTACHED TO STRUCTURES PROBABLY RESPONDS WITH THE STRUCTURE



EARTHQUAKE SHAKING EFFECTS

- PIPE SENSITIVE TO HORIZONAL & VERTICAL ACCELERATION, VELOCITY AND DISPLACEMENT
- DAMAGE THRESHOLD AT **MMI=VII** (ABOUT 0.15g; MAGNITUDE ~ 5.5) FOR CAST IRON
- DAMAGE THRESHOLD AT **MMI=VIII** (ABOUT 0.30g; MAGNITUDE ~ 6) FOR PE AND OLDER STEEL

EARTHQUAKE SHAKING EFFECTS

- PIPE MOST VULNERABLE AT

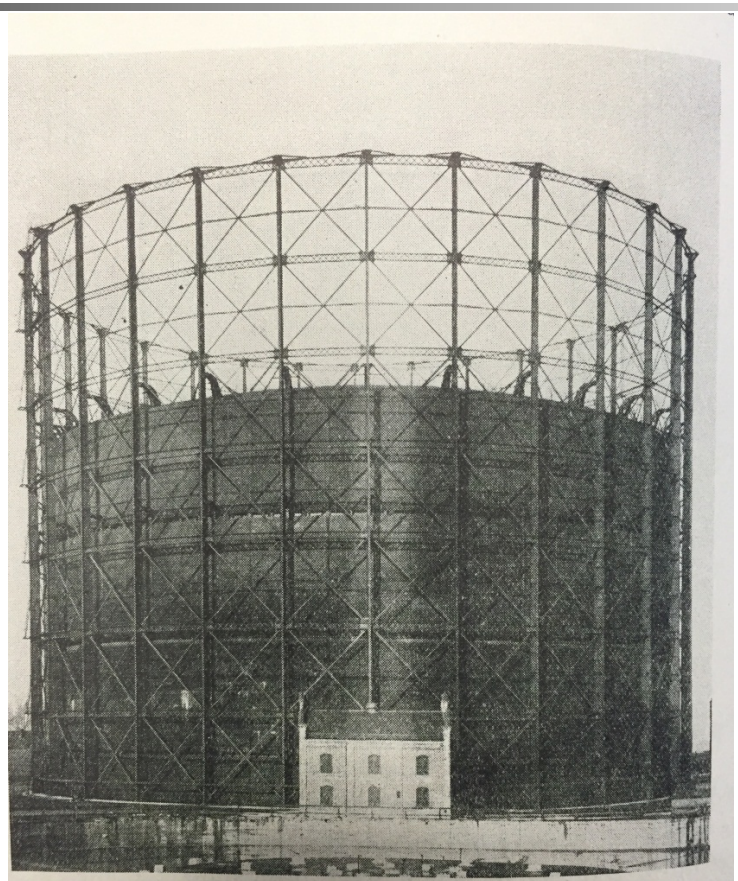
1. STRESS CONCENTRATORS (ELBOWS, VALVES, SIZE CHANGE, WALL THICKNESS CHANGE)
2. BELL & SPIGOT JOINTS (ON OLD CAST IRON)
3. COMPRESSION COUPLINGS
4. AREAS OF CORROSION
5. OXYACETYLENE WELDS (~PRE 1940)

EARTHQUAKE SHAKING EFFECTS

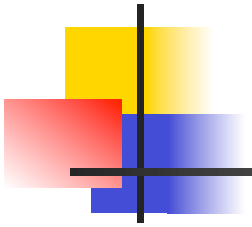
- LNG TANKS MAY BE VULNERABLE TO "ELEPHANT FOOT" BUCKLING- SIMILAR TO OIL TANKS
- CNG & LPG TANKS MAY BE VULNERABLE TO OVER-TURNING OR PIPE CONNECTION SHEARING
- OLD LOW PRESSURE WATER OR TAR SEAL HOLDERS ARE VULNERABLE TO CAP TILTING AND LEAKAGE OR CATASTROPHIC FAILURE

- ELEPHANT FOOT BUCKLING IN OIL TANKS

- “HORTON-SPHERE” DISPLACEMENT

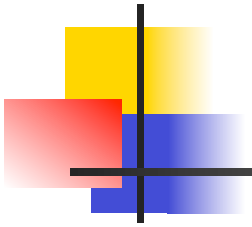


Astoria Holder of Consolidated Gas Co. of New York. (Courtesy of Bartlett Hayward Company, Baltimore, Md.)



LIQUEFACTION EFFECTS

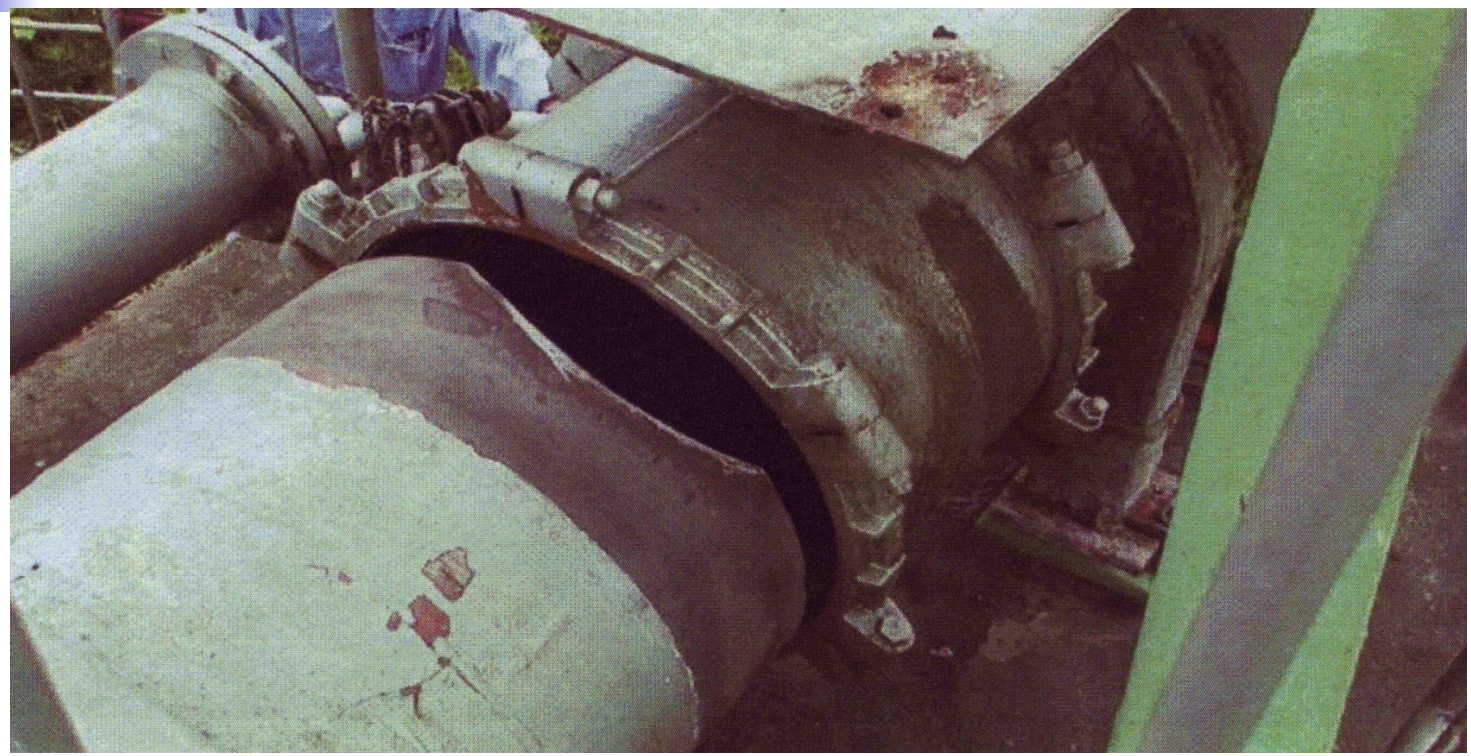
- BOUYANCY MAY CAUSE PIPE TO RISE SEVERAL FEET
- LATERAL SPREADING MAY CAUSE EXCESSIVE SHEAR STRESS AT BOUNDRIES, SIMILAR TO FAULTING
- LOOSE COHESIONLESS FILLS AT WATERFRONTS, ALLUVIAL FANS, ACTIVE FLOODPLAINS & RIVER CHANNELS PARTICULARLY SUSCEPTABLE



LIQUEFACTION EFFECTS

- AT SLOPES GREATER THAN 3 TO 5 DEGREES, SOIL FAILURE REPLICATES LANDSLIDES
- HEAVY WALL, CONCRETE COATED OR “WEIGHTED” WELDED PIPE LESS VULNERABLE TO BOUYANT FORCES
- STRESS CONCENTRATORS NEAR SHEAR BOUNDRIES INCREASE RISK
- COMPRESSION COUPLED & BELL AND SPIGOT PIPE EXTREMELY VULNERABLE

- LIQUEFACTION INDUCED SETTLEMENT



- LIQUEFACTION INDUCED COUPLING FAILURE

LANDSLIDE

- ROCK FALLS

1. TYPICALLY SURFACE EVENT
2. RISK TO PIPELINES LOW

- SLUMPS OR SHALLOW SLIDES

1. STRESS CONCENTRATORS NEAR SHEAR BOUNDRIES INCREASE RISK
2. SHALLOW PIPE DEPTH & LIGHT BACKFILL MAY PERMIT PIPE TO BREAK FREE OF SLIDE

LANDSLIDE

- DEEP TRANSLATION AND ROTATIONAL SLIDES

1. AFFECT LARGE AREAS WITH MASSIVE EARTH MOVEMENT
2. SIGNIFICANT GROUND COMPRESSION AT TOE
3. MAY BE POSSIBLE TO IDENTIFY POTENTIAL SLIDE AREAS
4. CONSIDER ISOLATION VALVES IN DESIGN

FAULT MOVEMENT

- PIPELINE MUST DEFORM LONGITUDINALLY AND IN FLEXURE TO ACCOMMODATE SURFACE OFFSETS
- LATERAL OFFSETS UP TO 27 FEET AND VERTICAL OFFSETS UP TO 14 FEET MAY OCCUR
- CLOSELY-SPACED PARALLEL FAULTS OR SPLAYS MAY EXIST
- ANTITHETIC FAULTING & GRABONS MAY OCCUR DURING VERTICAL (NORMAL) FAULTING EVENTS

FAULT MOVEMENT

- STRESS CONCENTRATORS WITHIN 1000 FT INCREASE PIPELINE VULNERABILITY
- DEPTH AND TYPE OF TRENCH BACKFILL EFFECT PIPELINE VULNERABILITY
- COMPRESSION COUPLED & BELL AND SPIGOT PIPE EXTREMELY VULNERABLE

- FAULT INDUCED PIPE DAMAGE

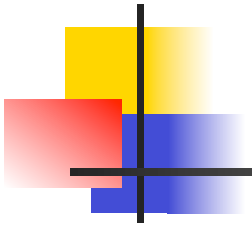
OPERATIONAL VULNERABILITIES

- SCADA (TELEMETERING) & COMMUNICATIONS SYSTEMS MAY BE COMPROMISED DUE TO POWER LOSS
- EMERGENCY RESPONSE TO LEAKS MAY BE COMPROMISED DUE TO BRIDGE OR ROAD CLOSURES
- DAMAGED “CO-LOCATED” INFRASTRUCTURE MAY IMPACT THE GAS SYSTEM

OPERATIONAL VULNERABILITIES

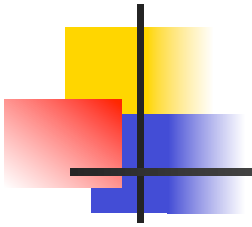
- OFFICE OPERATIONS WILL BE COMPROMISED BY SERIOUS BUILDING DAMAGE
- OFFICE OPERATIONS MAY BE COMPROMISED BY MINOR BUILDING DAMAGE:

1. SUSPENDED CEILING DAMAGE
2. TOPPLING OF COMPUTERS AND FILE CABINETS
3. WATER DAMAGE DUE TO DAMAGED FIRE SUPPRESSION SYSTEMS



OPERATIONAL VULNERABILITIES

- IT IS LIKELY THERE WILL BE LEAKAGE DUE TO MOBILE HOMES SHIFTING OFF FOUNDATIONS AT **MMI=VI** (ABOUT 0.07g; MAGNITUDE ~ 5.0)
- IT IS LIKELY THERE WILL BE LEAKAGE DUE TO RESIDENTIAL WATER HEATER FAILURES AT **MMI=VII** (ABOUT 0.15g; MAGNITUDE ~ 5.5)
- IT IS LIKELY THAT MANY CUSTOMERS WITHOUT LEAKS WILL TURN OFF THEIR GAS AT **MMI=VI**



SOME HISTORIC DATA

- 1971 SAN FERNANDO EARTHQUAKE (M=6.6, MMI=X)

1. 257 FAILURES OVER 690 MILES OF PIPE, 199 SERVICE PIPE FAILURES
2. 25,800 CUSTOMERS LOST SERVICE
3. 11 DAYS TO RESTORE SERVICE TO ALL CUSTOMERS

SOME HISTORIC DATA

- 1983 COALINGA EARTHQUAKE (M=6.6, MMI=VIII)

1. 4 FAILURES OVER 24 MILES OF PIPE
2. "NUMEROUS" GAS LEAKS DUE TO BUILDING COLLAPSE
3. 14 DAYS TO RESTORE SERVICE TO ALL CUSTOMERS (ENTIRE COMMUNITY OF APPROX. 7000 TOTAL POPULATION)

SOME HISTORIC DATA

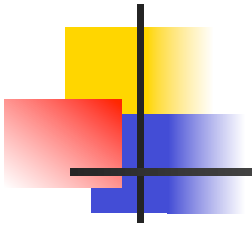
- 1987 WHITTIER NARROWS EARTHQUAKE (M=5.9, MMI=VIII)

1. 22 GAS MAIN LEAKS & 2000 LEAKS ON CUSTOMER PROPERTY
2. 21,000 CUSTOMERS, WITHOUT GAS RELATED DAMAGE, TURNED OFF THEIR GAS
3. 7 DAYS TO RETURN SERVICE TO ALL CUSTOMERS

SOME HISTORIC DATA

- 1989 LOMA PRIETA EARTHQUAKE (M=7.1, MMI=IX)

1. 88 PIPE FAILURES, 1,000 TOTAL LEAKS
2. 156,000 CUSTOMERS TURNED OFF THEIR GAS
3. 10 DAYS TO RESTORE SERVICE (WITH EXCEPTION OF HEAVILY DAMAGED MARINA DISTRICT)



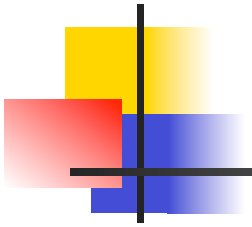
SOME HISTORIC DATA

- 1994 NORTHRIDGE EARTHQUAKE (M=6.7, MMI=X)

1. 585 PIPE FAILURES OVER 2,840 MILES OF PIPE
2. 15,021 SERVICE PIPE FAILURES
3. 135,800 CUSTOMERS, WITHOUT GAS RELATED DAMAGE, TURNED OFF THEIR GAS
4. 12 DAYS TO RESTORE SERVICE

EXPERIENCE HAS SHOWN THE HIGHEST SYSTEM VULNERABILITIES RELATE TO:

- CAST IRON PIPE
- OXYACETYLENE WELDED PIPE
- LOSS OF POWER & COMMUNICATIONS
- LOSS OF COMPUTER FUNCTIONS
- OLD BUILDINGS USED FOR CRITICAL FACILITIES
- OLD LOW PRESSURE GAS HOLDERS
- TOPPLING OF WATER HEATERS



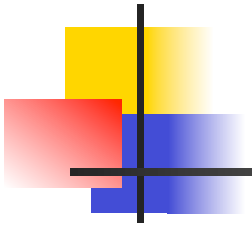
MITIGATION INCLUDES

- ACKNOWLEDGEMENT OF HAZARD & RISK

1. ACCESSING BOTH REGIONAL & LOCALIZED HAZARD
2. ACCESSING SYSTEM COMPONENT VULNERABILITIES

- SYSTEM RESPONSE MODELING

1. PREDICTING PIPE FAILURES
2. PREDICTING CUSTOMER EQUIPMENT/ STRUCTURE FAILURES



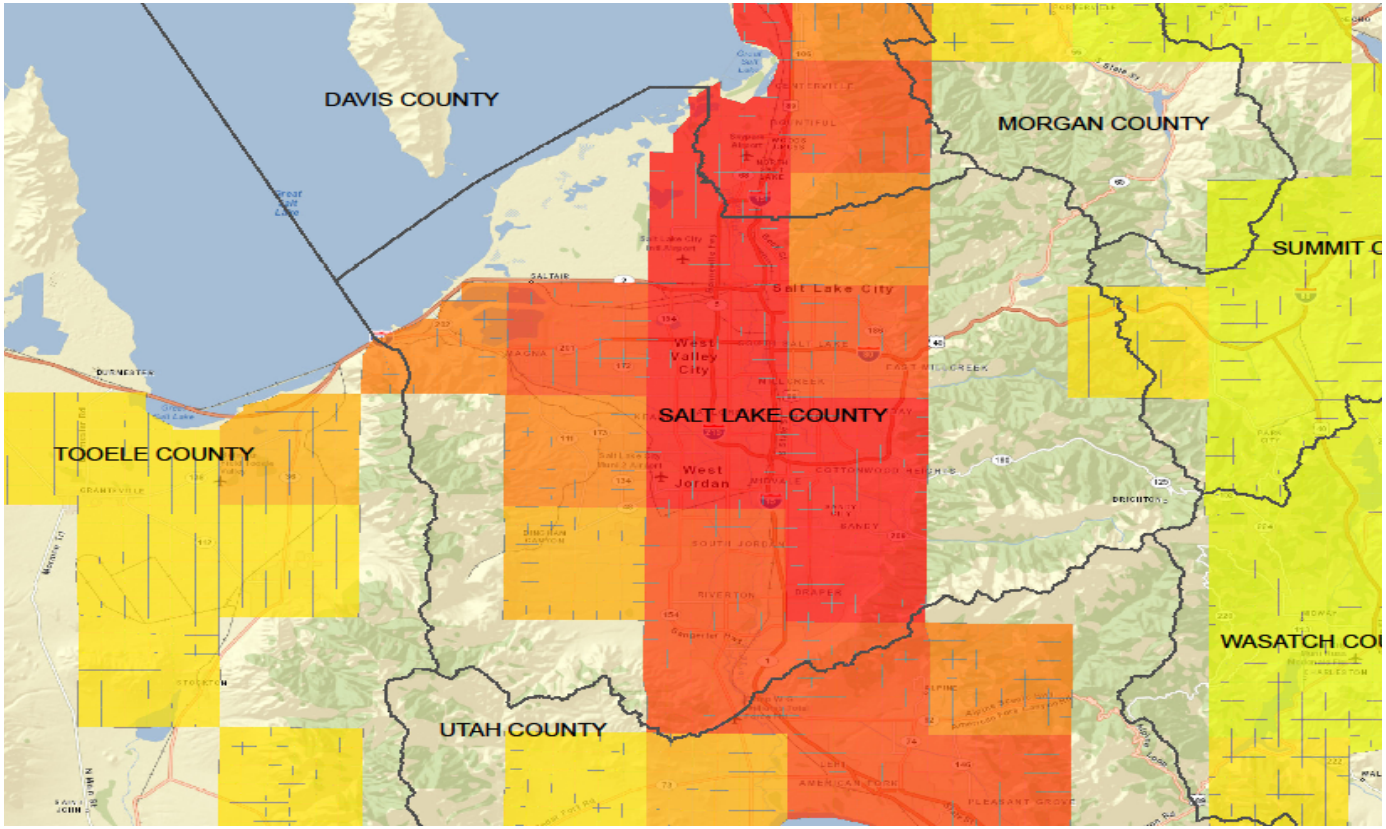
MITIGATION INCLUDES

- APPROPRIATE RETROFIT & DESIGN PRACTICES

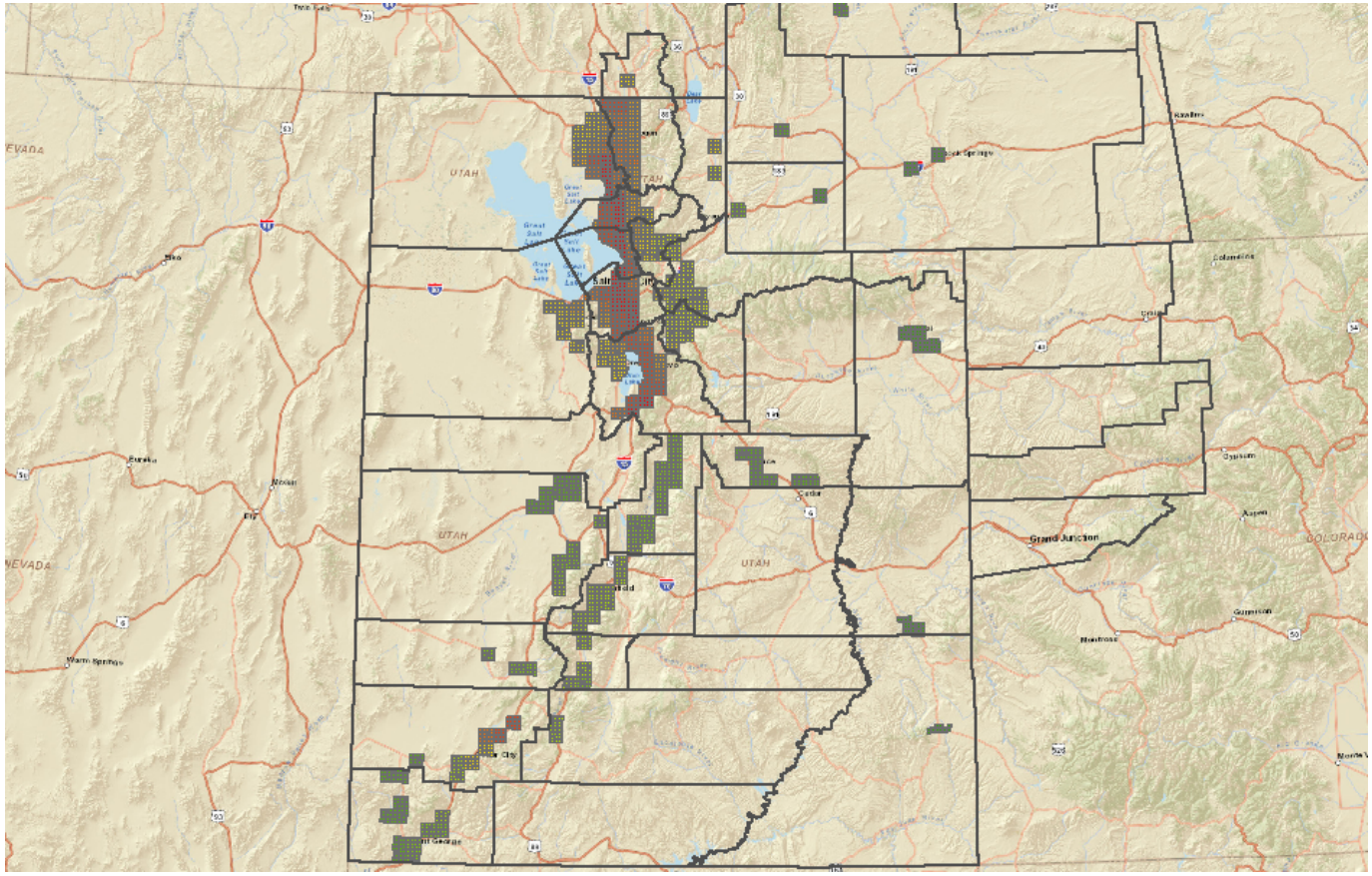
1. SETTING REALISTIC RETROFIT GOALS
2. INCLUDING SEISMIC CONSIDERATIONS IN NEW DESIGN

- EMPLOYEE & CUSTOMER TRAINING

1. SEISMIC PROVISIONS IN EMERGENCY PLAN
2. TABLE-TOP EXERCISES
3. CUSTOMER BROCHURES



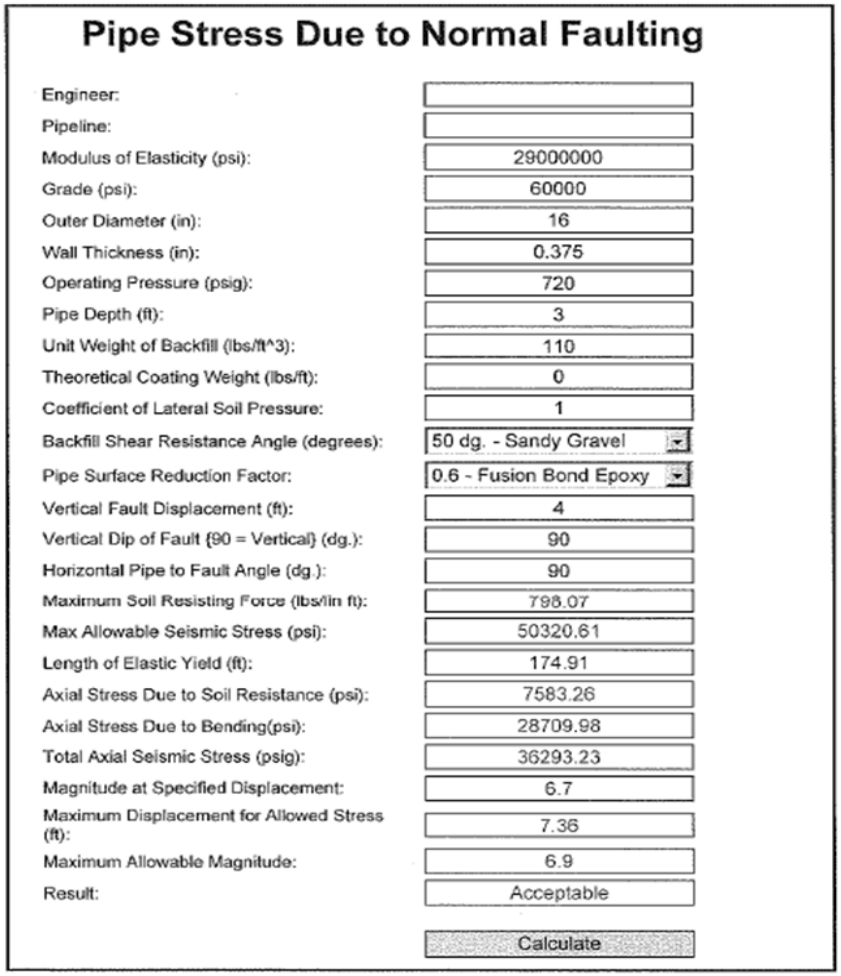
- PROBABILISTIC SHAKING INTENSITIES



- PROBABILISTIC SHAKING INTENSITIES

PIPE STRESS CAN BE CALCULATED AND MITIGATION PLANNED

- SHALLOW DEPTH
- 'V' DITCH
- SELECT BACKFILL
- GEOFOAM
- ADJUST PIPE GRADE OR WALL THICKNESS



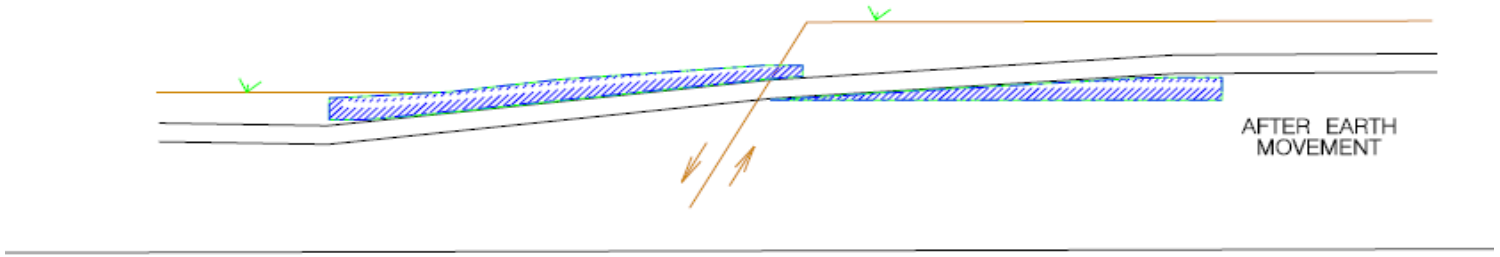
Pipe Stress Due to Normal Faulting

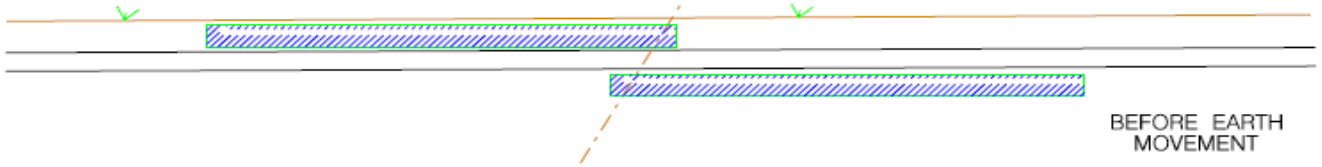
Engineer:	
Pipeline:	
Modulus of Elasticity (psi):	29000000
Grade (psi):	60000
Outer Diameter (in):	16
Wall Thickness (in):	0.375
Operating Pressure (psig):	720
Pipe Depth (ft):	3
Unit Weight of Backfill (lbs/ft^3):	110
Theoretical Coating Weight (lbs/ft):	0
Coefficient of Lateral Soil Pressure:	1
Backfill Shear Resistance Angle (degrees):	50 dg. - Sandy Gravel
Pipe Surface Reduction Factor:	0.6 - Fusion Bond Epoxy
Vertical Fault Displacement (ft):	4
Vertical Dip of Fault {90 = Vertical} (dg.):	90
Horizontal Pipe to Fault Angle (dg.):	90
Maximum Soil Resisting Force (lbs/lin ft):	798.07
Max Allowable Seismic Stress (psi):	50320.61
Length of Elastic Yield (ft):	174.91
Axial Stress Due to Soil Resistance (psi):	7583.26
Axial Stress Due to Bending(psi):	28709.98
Total Axial Seismic Stress (psig):	36293.23
Magnitude at Specified Displacement:	6.7
Maximum Displacement for Allowed Stress (ft):	7.36
Maximum Allowable Magnitude:	6.9
Result:	Acceptable

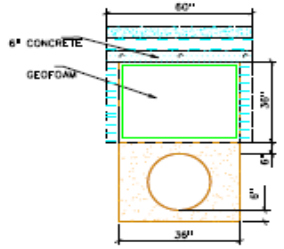
Calculate

- PIPELINE MITIGATION WORK MIGHT INCLUDE USING HIGH STRENGTH, HEAVY WALL PIPE

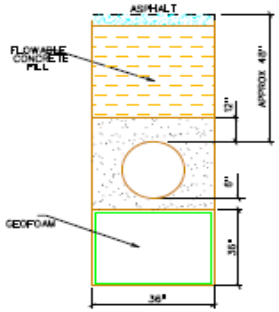
- BUTT WELDED STEEL PIPE IS VERY FLEXIBLE







ABOVE PIPE
GEOFOAM DETAIL



BELOW PIPE
GEOFOAM DETAIL

GEOFOAM CRUSHES AND DEFLECTS AFTER A MAJOR EARTHQUAKE

- INSTALLING GEOFOAM

- INSTALLING GEOFOAM

- Polyethylene Pipe
- Excess Flow Valves
- Isolation Valves
- Regulator Station Valves

PROTECTION OF PIPELINES FROM PERMANENT GROUND DEFORMATION USING EPS GEOFOAM

Steven F. Bartlett
Department of Civil and Environmental Engineering, University of Utah,
110 Central Campus Drive, Salt Lake City, Utah, 84112
bartlett@civil.utah.edu

ABSTRACT

Expanded polystyrene (EPS) geofoam is an ultra-light geosynthetic that can be incorporated in transportation infrastructure to reduce horizontal and vertical stresses imposed on buried culvert and pipeline systems at fault crossings and other locales of permanent ground deformation. EPS reduces these stresses via two important mechanisms: (1) weight reduction, and (2) compressible inclusion. This paper summarizes four EPS block configurations that have been implemented in roadway and rail systems to protect buried pipelines and culverts: (a) light-weight cover or embankment constructed over pipe or culvert, (b) "imperfect trench method" with compressible inclusion EPS block placed above pile or culvert, (c) slot-trench light-weight cover system with EPS block placed in slot, and (d) EPS post and beam system with head space void.

INTRODUCTION

Expanded polystyrene (EPS) geofoam is a type of cellular geosynthetic used in both above and below ground applications in geotechnical and civil engineering. Its primary uses are: road construction over poor soils; roadway widening; light-weight embankment for bridge abutments and bridge underfill; light-weight rail embankments; protection of pipelines, culverts and buried structures; compensating foundations; landscaping and green roofs; slope stabilization; stadium and theater seating; levees; airport and runway/taxiways; and other specialized applications (Stark and others, 2012).

The process for manufacturing EPS was developed in the 1950s, and the first below ground application was the insulation of foundation walls for residential housing in Scandinavia during the 1960s. In addition, geofoam has been placed under pavements in Scandinavia, Canada, and the United States to prevent seasonal freeze-thaw. In the 1970s, EPS embankment construction using geofoam blocks was introduced as an ultra-lightweight fill in the United States and Norway to reduce settlement and improve bearing capacity of roadways. Most notably in 1972, the Norwegian Road Research Laboratory (NRRL) placed geofoam blocks in the approach fill of the Flom Bridge to reduce differential settlement between the approach and bridge (Alfhein and others, 2011). Since that time, NRRL has continued research and long-term monitoring programs at this and others locations. Such studies have greatly added to the understanding of EPS and its long-term performance (Aabøe and Frydenlund, 2011).

Although EPS block are referred to in this paper as "geofoam," other types of polystyrene have been used to manufacture geofoam block (e.g., extruded polystyrene). EPS block are created during a two-stage process. In the first stage, tiny polystyrene resin beads are expanded using a hydrocarbon-blowing agent (i.e., pentane gas) that is contained within each bead. During this stage, the beads are exposed to steam causing a softening of the resin and the subsequent expansion of the bead by the pentane gas. This creates a cellular structure within each bead which is called "pre-puff." After a short stabilization period, the pre-puff is placed in a large block mold and steam is injected causing additional expansion and the beads to coalesce. The result, upon cooling, is a relatively solid block of light-weight material that has a closed, air-filled, cellular structure. Individual cells (i.e., remnants of the beads) are still visible after the block molding process, but the beads have completely coalesced to form a closed fabric with essentially no void between the cells. Block molds typically produce geofoam block that ranges from 500 to 600 mm high, 1 to 1.2 m wide and 2 to 5 m long. Geofoam block can be hot-wire cut at the manufacturing plant or cut by hand in the field to the required size and shape during block installation.

PROTECTION OF PIPELINES AND CULVERTS

This paper discusses methods that can be deployed to protect pipelines and culverts from potential damage resulting from soil stresses caused by vertical permanent ground displacement (VPGD) or other sources. The source(s) of VPGD may originate

from multiple mechanisms associated with soft or weak foundation soil conditions, or with other issues associated with the nature and construction of embankment or trench backfill materials (e.g., primary consolidation settlement, settlement induced by wetting or by improper compaction techniques and construction moisture control, settlement from collapsible soils or volume changes due to shrinkage or swell of highly plastic soils, landsliding and other forms of mass movement and slope instability, and tectonic deformation (i.e., surface-fault rupture).

There are two important material properties of geofoam that make it beneficial for protecting buried pipelines and culverts from the deleterious effects of VPGD: (1) its ultra-light unit weight when compared with that of earthen materials, and (2) its well-defined compressibility characteristics, which allow for controlled compression and yielding while maintaining much of its original shape and size. Regarding the first, geofoam has an extremely low mass density (12 to 45 kg/m^3) when compared with earthen materials. This property can be used to dramatically decrease overburden stresses on buried systems. Regarding the second, when used a "compressible inclusion" (Horvath 1996, 1997) in buried geosystems, geofoam can significantly reduce the vertical and horizontal pressures on pipelines, culverts, and retaining and buried walls due to its relatively low stiffness when compared with many compacted, earthen materials. The Young's modulus of geofoam, as used in civil engineering practice, varies from about 15 to 128 kPa (ASTM D6817) depending on the particular product selected. When a compressible inclusion is placed above a buried pipeline or culvert, it creates a less stiff zone (i.e., inclusion) in the soil matrix. As the soil and other loads are applied, the inclusion compresses resulting in a significant redistribution of stresses in the soil adjacent to the inclusion as the soil's internal shear strength is mobilized.

The ultra-light-weight and compressible inclusion properties of geofoam can be used to develop lightweight embankment, backfill, and cover systems that are engineered and constructed in concert with the soil and pavement systems to protect vital conveyance systems from potential overstressing, damage, and/or rupture resulting from VPGD. Such protective systems are often constructed without the need for additional ground improvement of the foundation soils. Figure 1 shows conceptual sketches of some of the strategies that have been evaluated, constructed, and monitored in the geotechnical literature. Methods shown in figures 1a and 1b are more developed in that the design and construction techniques have been explored by many researchers. Configurations shown in figures 1c and 1d are more recent and these strategies are under current research and development.

LIGHT-WEIGHT EMBANKMENT STRATEGY

Light-weight EPS embankments similar to that of figure 2 constitute one of the primary means of protecting buried systems from overstressing due to VPGD, or from other overburden, or compaction-related stresses (Bartlett and others, 2012). Because of the extremely light-weight nature of geofoam, the overburden stress solely consists of the weight of any overlying pavement section or rail materials (ballast, sleepers, etc.). Also, such systems are highly effective in redistributing live (i.e., traffic) loads so that these are not usually a governing issue in determining the design and performance of the pipe and/or culvert system. Some common features and considerations associated with the type of construction shown in figure 1a are: (1) prior to placement of the geofoam, sub-excavation of the foundation soils is often performed by removing sufficient material that is equal to the weight of the geofoam and overlying roadway section; thereby creating a "zero net" vertical load or "compensating" condition. This improves the bearing capacity and reduces the potential for subsequent settlement of the system, (2) a non-woven geotextile and bedding sand are placed in the excavation to create a level, stable base for the placement of the EPS block, (3) the geofoam blocks are placed in alternating directions in each consecutive layer and the vertical edges of the block are offset so not to create continuous vertical seams in the embankment, (4) the adjacent earthen side slopes are sufficiently sloped or cut back to ensure slope stability, thus precluding any possible transfer of significant horizontal force to the geofoam mass from the earthen side slope, (5) the roadway section and geofoam modulus are selected and designed to prevent any localized overstressing of the EPS from the combination of live loads and dead loads imposed at the surface, (6) the top and side slopes of the geofoam embankment are often protected by a petroleum resistance geomembrane and topsoil cover to guard against ultraviolet light damage and the potential for chemical attack from diesel or gasoline spills, and (7) global and internal stability of the system are checked using the appropriate design guidance and review process approved by the oversight agency (Bartlett and others, 2012).

IMPERFECT TRENCH STRATEGY

The earth pressure imposed on deeply buried culverts and pipes is significantly affected by soil arching. Both the magnitude and distribution of earth pressure on buried culverts depend on the relative stiffness of the culvert and the soil. The so-called

imperfect trench method (also called induced trench or imperfect ditch method) involves installing a compressible inclusion above the relatively rigid culvert or pipeline (figure 1b). As the earthen embankment is constructed, the soft zone caused by the compressible inclusion compresses more than the surrounding fill; thus inducing positive arching above the culvert (Vaslestad and others, 2011). The deformation in the compressible inclusion provides mobilization of the shear strength of the soil above the culvert, and as a consequence the vertical earth pressure remains lower than the overburden pressure resulting from the weight of the soil.

EPS geofoam blocks have been evaluated and/or used for load reduction on buried rigid pipes under highway fills since 1988 in Norway (figure 3), and in many other studies since that time (Vaslestad, 1990; Roh and others, 2000; Yang and Yongxing, 2005; Gu and others, 2005; Zhang and others, 2006; Kang and others, 2007; Sun and others, 2009; McGuigan and Valsangkar, 2010). The properties of soil-structure interaction in the buried culverts highly depend on the mechanical properties of the backfill material and the stiffness of the compressible material (i.e., geofoam in this case). The Norwegian Public Roads Administration (NPRA) has instrumented four locations and monitored the reduction in vertical stress (Vaslestad and others, 1990, 2011; Vaslestad and others, 2009). These studies show that the long-term measured vertical pressure above the crown of the pipe ranged from 23% to 25% of the overburden pressure for installations with granular backfill material, and about 45% for the installations with cohesive soil backfill. It found that the performance of the induced arch was largely affected by the type of soil used in the embankment construction. Field installations with granular fill reduced the vertical pressure over the culvert more than those with silty-clay embankment. Nonetheless, the measured earth pressure for the section of culvert without the induced trench installation showed pressure that was 124% of the calculated overburden pressure. The final compression of the EPS geofoam block at the end of embankment construction ranged from 27% to 32% for concrete pipes with granular fill, and 50% for cast-in-situ box culvert with cohesive fill.

Figure 4 shows a typical installation schematic for the imperfect trench method as recommended by NPRA (2010). The compressible inclusion utilized EPS block with a density of 20 kg/m^3 and a compressive resistance of 100 kPa at 5% strain. The recommended width of the EPS block is 1.5D, where D is the diameter of the pipe and the recommended thickness of the EPS block is 0.5 m. The block is placed 0.2 D above the top of the pipe. The recommended minimum earthen cover above the compressible inclusion, H, is 5 m, or greater, and it is recommended that the granular backfill material be compacted to 97% of the standard Proctor value. In addition, it is recommended that D/3 uncompacted zone be used at the base of the pipe (figure 4). Additional information regarding the evaluation and construction of this type of system can be found in Vaslestad (1990), NPRA (2010), and Vaslestad and others (2011). Numerical evaluation methods are described in Vaslestad (1990), Vaslestad and others, (2009), and Sun and others, (2009).

SLOT TRENCH COVER SYSTEM STRATEGY

Very little research and experimental work has been done regarding the use of geofoam to protect buried pipelines from VPGD resulting from vertical tectonic fault offset. Choo and others (2007) and Lingwall (2011) have explored the use of geofoam as a light-weight cover system for buried, ductile steel pipelines subjected to vertical fault offset. Choo and others (2007) used centrifuge testing of scaled models to evaluate the benefits of geofoam in reducing pipeline stresses undergoing vertical offset.

The design concept developed by Lingwall (2011) and Bartlett and Lingwall (2014) was to use the light-weight and compressible nature of EPS geofoam to reduce the vertical, bending, and shear forces induced on a ductile-steel, high pressure, natural gas pipeline system resulting from vertical offset associated with normal faulting in an urban Utah roadway. Because of the relatively shallow burial of the planned pipeline (2 to 3 m), the construction strategy was to place EPS blocks atop the pipe in the trench excavation (figures 1c and 5) in a reach of highway that crossed the fault trace on the hanging wall (i.e., down-dropped) side of the normal fault. It was hoped that an EPS cover system so constructed would create an EPS-infilled, light-weight vertical "slot" within the trench that would accommodate upward relative movement of the pipeline during fault rupture (figures 5 and 6). It was hypothesized that the compression and uplift of the EPS block placed in the slot by the pipeline would significantly decrease the bending stress that developed in the pipe when compared with the potential interaction with traditional trench backfill materials.

However, key to this design concept is the assumption that any buckling damage to the overlying asphaltic pavement from "controlled" uplift of the pipeline was acceptable post-earthquake performance as long as the pipeline remained undamaged. In addition, it became evident that a segment of the pipeline near the fault trace may be partially exposed following the earthquake. The mitigative strategy and potential post-earthquake performance were discussed with the local natural gas utility

and the Utah Department of Transportation (UDOT), which owned the roadway, and were deemed acceptable by the project team. Finally, because the geofoam blocks were to be placed under the roadway, the cover system design had to support live traffic loads without potential overstressing the EPS block or underlying pipe.

GEOFOAM POST AND BEAM COVER SYSTEM STRATEGY

Although the slot trench geofoam cover system was successful in reducing the stresses imposed on pipe systems undergoing vertical offset, this remedial strategy will not be successful for non-ductile, or more fragile pipe systems and other solutions must be sought. For example, an interesting emergency situation arose which called for a modification to this concept. In December 2013, a severed sewer pipeline underneath a roadway at a Utah ski resort (figure 7 left) required an innovation to the light-weight slot trench cover concept. The sewer pipe had undergone two episodes of rupture resulting from the dewatering of a deep, sandy soil layer underneath the pipe. The dewatering resulted in subsidence in this area, and deep cracks and fissures were observed in the nearby and underlying ground. During the first repair, approximately 0.25 m of consolidation settlement and 0.15 horizontal movement were measured at the lowest point of the damaged line.

Based on discussions with the owner, it was evident that continued subsidence in this area was expected and that such settlement would continue to damage the pipeline without a significant intervention. Therefore, a strategy to create a 0.6 m headspace void above the pipeline was evaluated and constructed (figures 1d and 7 middle). This configuration of geofoam block would allow for settlement of the foundation soil without imposing significant soil loads to the pipe system. To prevent possible damage to the pipeline from sagging under its own weight, a hanger system was employed with an adjustable rod (figures 1d and 7 right).

The 0.6-m headspace void was created by placing EPS blocks on both sides of the pipeline to function as "posts." An EPS block capping "beam" was placed atop these posts to cover the void space. The beam was capped with 100-mm thick, reinforced, pre-cast panel concrete panel (figure 7 right). The steel-rod pipe hangers were periodically attached to the pipe via steel rings and extended through the pre-cast panel where they could be accessed and adjusted via manhole covers.

From an EPS design standpoint, it was important to determine that the posts and beam would not be overstressed from the design live traffic load. The EPS density selected for this situation was EPS29, which has a compressive resistance of about 75 kPa at 1% axial strain (ASTM D6817). This compressive resistance value was used as the allowable vertical stress in the design of the posts and overlying beam.

Although this design and construction of the post and beam geofoam cover was done under emergency situations, the design concept and system appear to have been successful. No further rupture of the sewer line has occurred in a 1-year post-construction period. Research and further evaluations and configurations of this system are on-going.

CONCLUSIONS

The consequences of permanent ground displacement and other soil loads and interactions pose a significant threat to buried culverts and pipelines. The potential damage to such systems can be significantly reduced by constructing light-weight cover or trench backfill system using EPS geofoam. This can be done such that the buried conveyance system can withstand permanent ground deformation induced from multiple mechanisms. To this end, innovative EPS geofoam cover and trench backfill systems have been described and evaluated in this paper. These systems take advantage of the light-weight and compressible properties of EPS geofoam to reduce induced vertical and horizontal stresses on buried culvert/pipe line systems from overlying dead and live loads. In most instances, the evaluation of geofoam/soil/culvert/pipe systems involves significant interaction between these materials, which can best be evaluated using numerical techniques.

ACKNOWLEDGEMENTS

Gratitude is extended to Questar Gas and Bechtel Corporations for funding the research associated with steel pipeline protection using an EPS slot trench cover systems. Much of the research for the slot trench cover systems was evaluated by Bret

Lingwall as part of his Ph.D. dissertation. ACH Foam Products of Murray, Utah donated the EPS block used in the field tests described herein. Dr. Aurel Trandafir of the University of Utah assisted in the testing of geofoam cylinders and block specimen, and development of the complex hyperbolic model for the EPS geofoam. Timothy Mitchell of the University of Utah assisted in the pipe interaction experiments and modeling, and Byron Foster of the University of Utah assisted with the full-scale uplift tests.

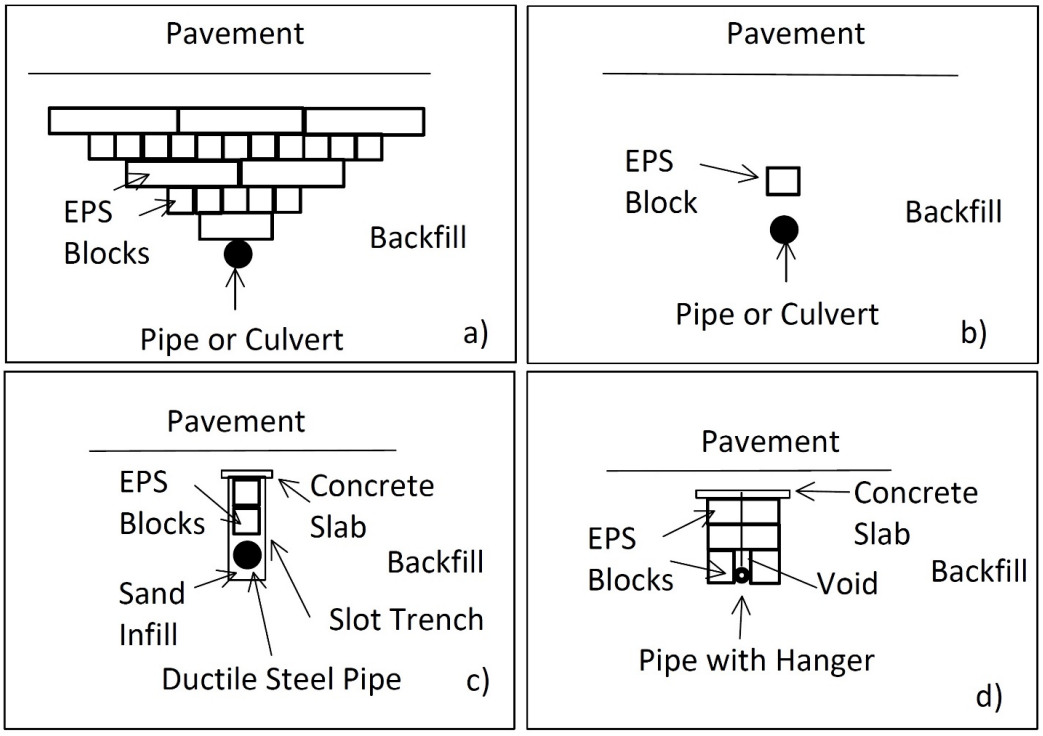


Figure 1. *General methods of protecting pipelines and culverts from vertical ground displacement: (a) light-weight cover or embankment constructed over pipe or culvert, (b) "imperfect trench method" with compressible inclusion EPS block placed above pile or culvert, (c) slot-trench light-weight cover system with EPS block placed in slot, and (d) EPS post and beam system with head space void.*

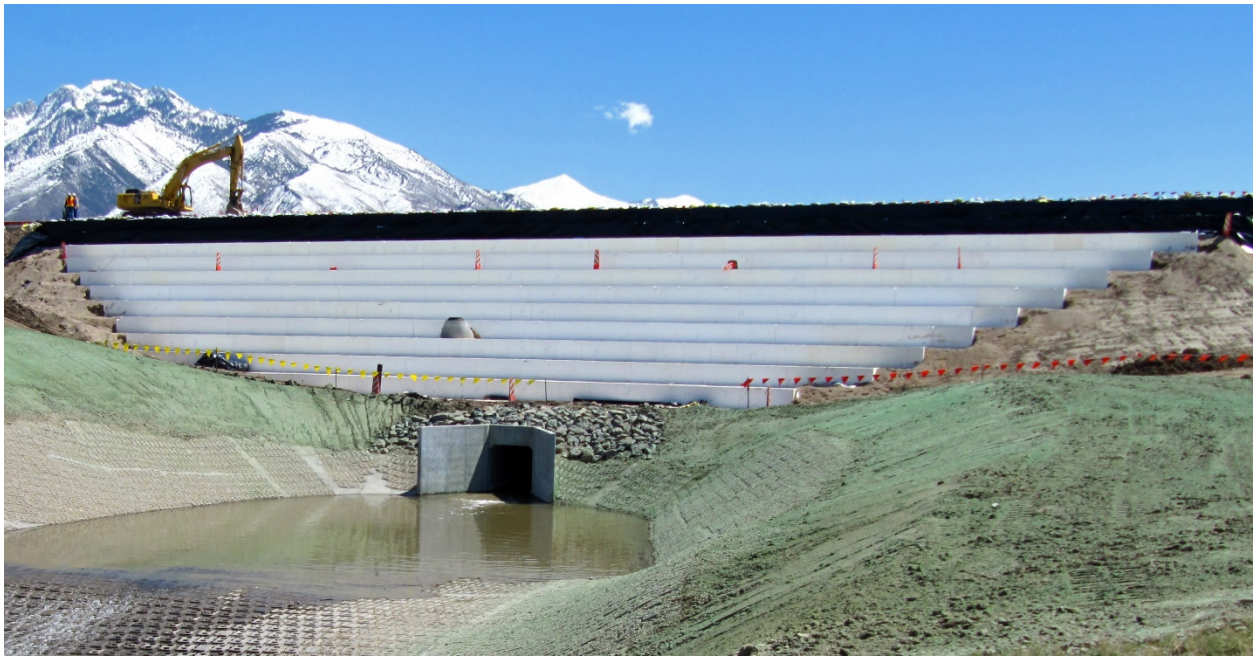


Figure 2. *Light-weight EPS geofoam embankment constructed over culvert system, Utah Transit Authority Frontrunner Commuter Rail System, Draper, Utah (photo courtesy of ACH Foam Products, Murray, Utah).*

Figure 3. *Imperfect trench method with EPS geofoam compressible inclusion placed atop concrete pipe. Pressure plate instrumentation visible in foreground, Eidanger, Norway 1988 (photo courtsey of Norwegian Public Roads Administation).*

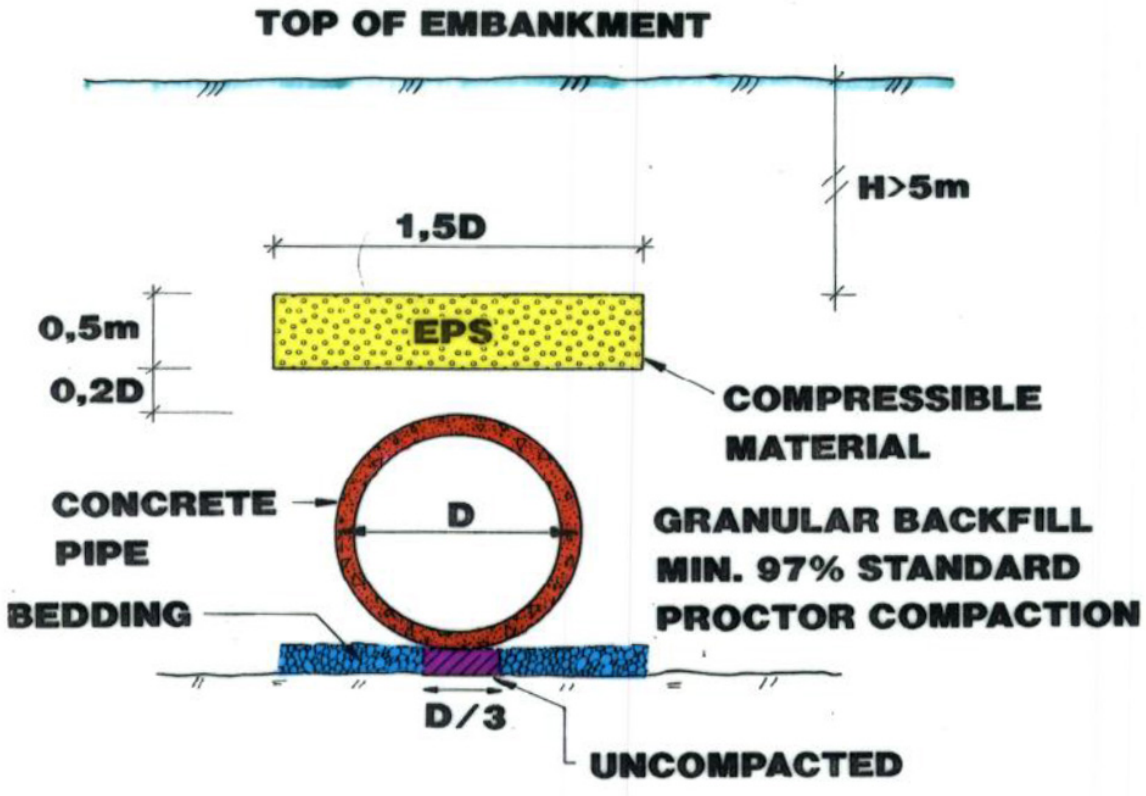


Figure 4. *Recommended pipe and EPS layout for imperfect trench method (after Vaslestad and others, 2011).*

Figure 5. *EPS slot-trench, light-weight cover system constructed across the Wasatch fault zone in Salt Lake City, Utah in the middle of roadway at 500 South Street. Left photo shows placement of 0.6-m diameter ductile steel pipe in slot trench in roadway. Middle photo shows placement of EPS geofoam atop the pipeline with a geomembrane cover. Right photo shows the construction of reinforced concrete load distribution slab (LDS) poured atop the EPS and geomembrane. Lastly, pavement section was constructed to finish roadway (not shown).*

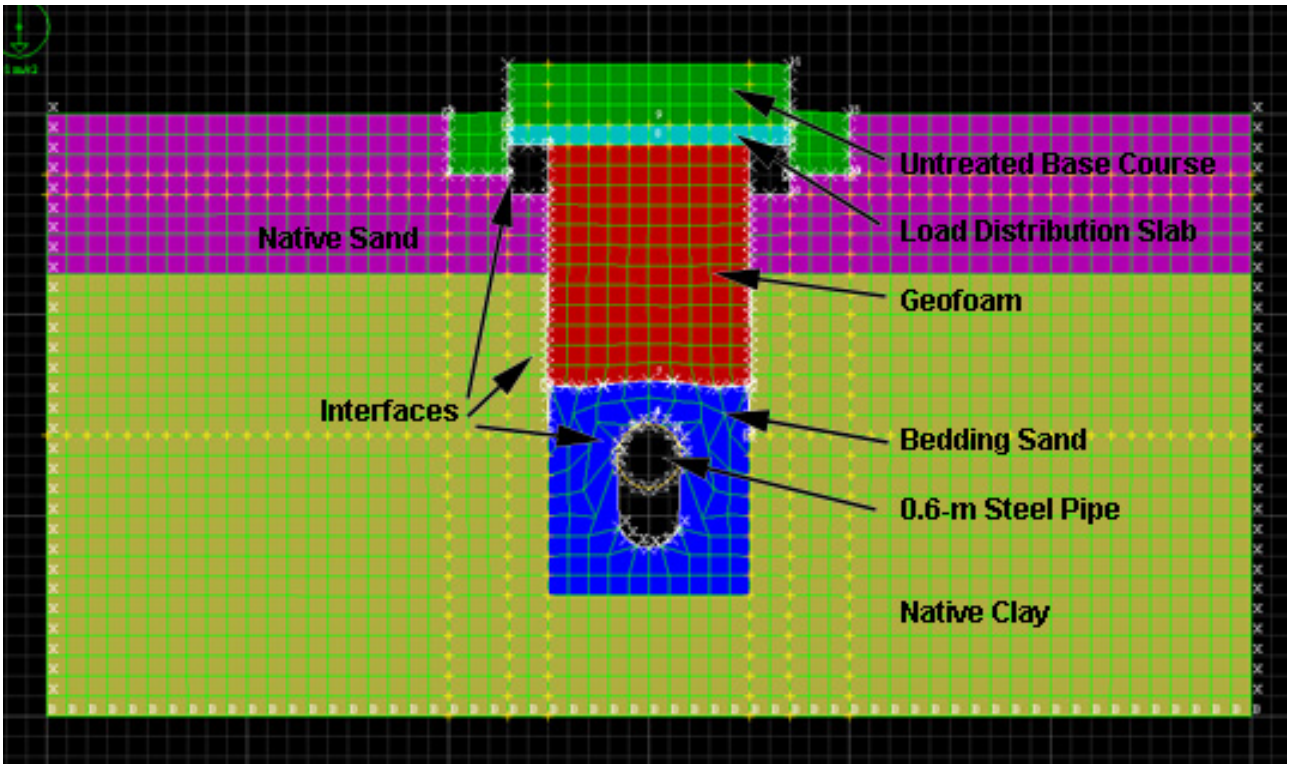


Figure 6. *Numerical model developed to evaluate full-scale uplift test of pipe interaction with light-weight geofoam cover (Lingwall, 2011).*

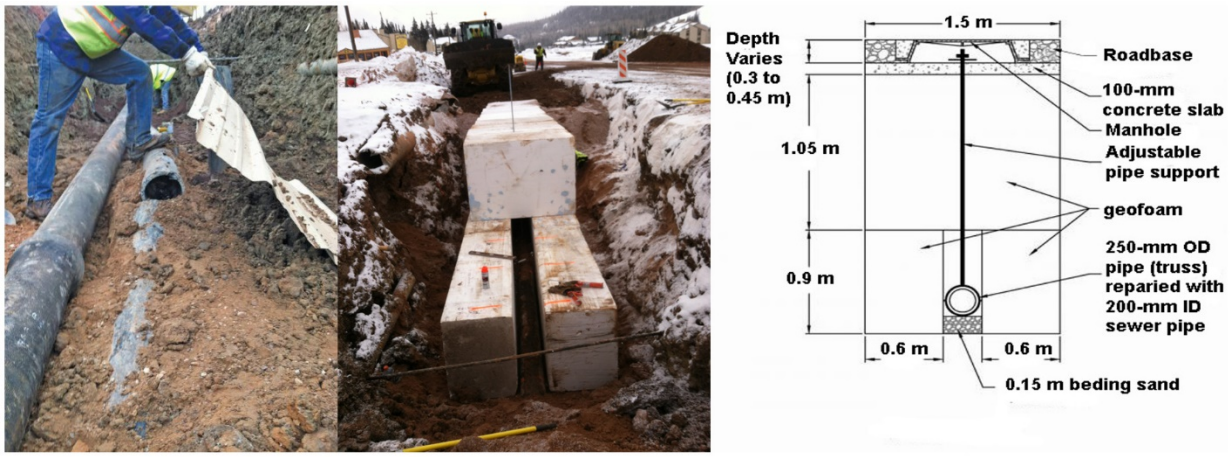


Figure 7. *Geofoam "post and beam" system with head space void. Damaged pipe (left). Construction of post and beam cover (middle). Schematic drawing of post and beam cover system (right).*

REFERENCES

Aabøe, R., and Frydenlund, T.E., 2011, 40 years of experience with the use of EPS geofoam blocks in road construction: Proceedings of EPS 2011, June 6th–8th at Lillestrøm, Norway, v. 1, paper 48, 14 p.

Alfhein, S., Flaate, K., Refsdal, G., Rygg, N., and Aarhus, K., 2011, The first EPS geoblock road embankment—1972: Proceedings of EPS 2011, June 6th–8th 2011 at Lillestrøm, Norway. v. 1, paper 2, 10 p.

ASTM D 6817-07. Standard Specification for Rigid, Cellular Polystyrene Geofoam.

Bartlett, S.F., Lawton, E.C., Farnsworth, C.B., and Newman, M.P, 2012, Design and evaluation of expanded polystyrene geofoam embankments for the I-15 reconstruction project, Salt Lake City, Utah: Draft report prepared for Utah Department of Transportation Research Division, University of Utah, Department of Civil and Environmental Engineering, 203 p.

Bartlett, S.F., and Lingwall, B.N, 2014, Protection of lifelines and buried structures using EPS geofoam: GeoShanghai, International Conference sponsored by Tongji University, ASCE Geo-Institute and Transportation Research Board, Shanghai, China, May 26th–28th, 2014: ASCE Geotechnical Special Publication, No. GSP 238, 10 p.

Choo, Y.W., Abdoun, T.H., O'Rourke, M.J., and Da, H., 2007, Remediation for buried pipeline systems under permanent ground deformation: Soil Dynamics and Earthquake Engineering v. 27, p. 1043–1055.

Gu, A., Guo, T., and Wang, X., 2005, Experimental study on reducing-load measurement using EPS of culvert under high-stacked soil: Chinese Journal of Geotechnical Engineering, 2005-05.

Horvath, J.S., 1996, The compressible inclusion function of EPS geofoam—An overview: Proceedings International Symposium on EPS Construction Method (EPS Tokyo '96), Tokyo, Japan, published by the EPS Construction Method Development Organization (EDO), Tokyo, Japan, p. 71–81.

Horvath, J.S., 1997, The compressible inclusion function of EPS geofoam: Geotextiles and Geomembranes, v. 15, no. 1-3, p. 77–120.

Kang, J., Parker, F., and Yoo, C., 2007, Soil-structure interaction and imperfect trench installations for deeply buried concrete pipes: Journal of Geotechnical and Geoenvironmental Engineering, v. 133, no. 3, p. 277–285.

Lingwall, B.N., 2011, Development of an expanded polystyrene geofoam cover system for pipelines at fault crossings: Salt Lake City, Utah, University of Utah, Department of Civil and Environmental Engineering, Ph.D. dissertation, 432 p.

McGuigan, B.L., and Valsangkar, A.J., 2010, Earth pressures on twin positive projecting and induced trench box culverts under high embankments: Canadian Geotechnical Journal, v. 47, no. 2, p. 147–163, 10.1139/T09-085.

Roh, H.S., Choi, Y.C., and Kim, S.H., 2000, Earth pressures on culvert during compaction of backfill: Melbourne, Australia, International Society for Rock Mechanics Symposium, Nov. 19–24, 2000.

Stark, T.D., Bartlett, S.F., and Arellano, D., 2012, Expanded polystyrene (EPS) geofoam applications and technical data: The EPS Industry Alliance, 1298 Cronson Blvd., Suite 201, Crofton, MD 21114, 36 p.

Sun L., Hopkins, T.C., and Beckham, T.L., 2009, Reduction of stresses on buried rigid highway structures using the imperfect ditch method and expanded polystyrene (geofoam): Research Report KTC-07-14/SPR-228-01-1F, Kentucky Transportation Center, University of Kentucky, Lexington Kentucky, 49 p.

Vaslestad, J., 1990, Soil structure interaction of buried culverts: Doktor Ingenioravhandling 1990:7 Institute for Geotechnics, University of Trondheim, 452 p.

Vaslestad, J., Yesuf, G.Y., Johansen, T.H., Damtew, T., and Wendt, M., 2009, Instrumented field test and soil structure interaction of concrete pipe with high fill, *in* 17th International Conference on Soil Mechanics and Geotechnical Engineering: Alexandria, Egypt, ISO Press Ebooks, p. 1802–1805.

Vaslestad, J., Sayd, M.S., Johansen, T. H., Wiman, L., 2011, Load reduction and arching on buried rigid culverts using EPS geofoam—Design method and instrumented field tests: Proceedings of EPS 2011, June 6th–8th 2011 at Lillestrøm, Norway, v. 1, paper 36, 10 p.

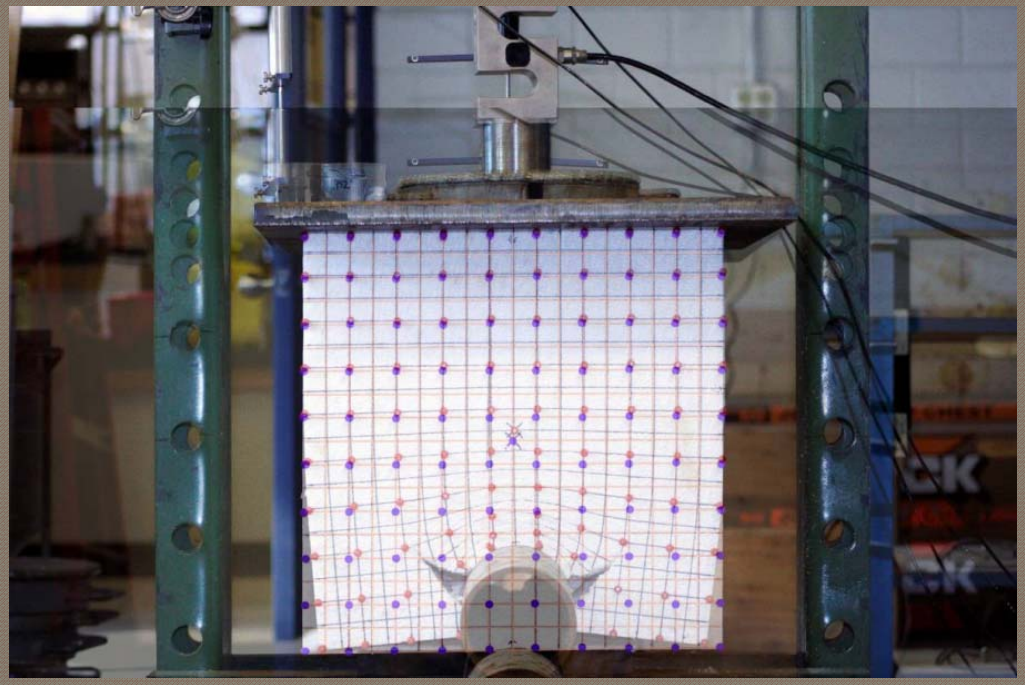
Yang, X., and Yongxing, Z., 2005, Load reduction method and experimental study for culverts with thick backfills on roadways in mountainous regions: China Civil Engineering Journal, v.38, no. 7, p. 116–121.

Zhang, W., Liu, B., and Xie, Y., 2006, Field test and numerical simulation study on the load reducing effect of EPS on the highly filled culvert: Journal of Highway and Transportation Research and Development, China, v. 23, no. 12, p. 54–57.

The following is a PDF version of the author's PowerPoint presentation.

Protection of Pipelines from Permanent Ground Deformation Using EPS Geofoam

BASIN AND RANGE PROVINCE SEISMIC HAZARDS SUMMIT III



Steven F. Bartlett, Ph.D. P.E
Associate Professor
bartlett@civil.utah.edu

THE UNIVERSITY OF UTAH

Topics

- Introduction to EPS
- Seismic Hazards
- Pipeline Protection Strategies
- Development of EPS Light-weight Cover
- Test Results
- Field Application

THE UNIVERSITY OF UTAH

Beginnings of Geofoam in Civil Engineering Applications

Flom Bridge – 1972 - Norway

THE UNIVERSITY OF UTAH

Geofoam Properties

ASTM D6817 Physical Property Requirements of EPS Geofoam

Type	EPS12	EPS15	EPS19	EPS22	EPS29	EPS39	EPS46
Density, min., kg/m^3(lb/ft^3)	11.2 (0.70)	14.4 (0.90)	18.4 (1.15)	21.6 (1.35)	28.8 (1.80)	38.4 (2.40)	45.7 (2.85)
Compressive Resistance, min., kPa (psi) at 1 %	15 (2.2)	25 (3.6)	40 (5.8)	50 (7.3)	75 (10.9)	103 (15.0)	128 (18.6)
Compressive Resistance, min., kPa (psi) at 5 %	35 (5.1)	55 (8.0)	90 (13.1)	115 (16.7)	170 (24.7)	241 (35.0)	300 (43.5)
Compressive Resistance, min., kPa (psi) at 10 %[A]	40 (5.8)	70 (10.2)	110 (16.0)	135 (19.6)	200 (29.0)	276 (40.0)	345 (50.0)
Flexural Strength, min., kPa (psi)	69 (10.0)	172 (25.0)	207 (30.0)	240 (35.0)	345 (50.0)	414 (60.0)	517 (75.0)
Oxygen index, min., volume %	24.0	24.0	24.0	24.0	24.0	24.0	24.0

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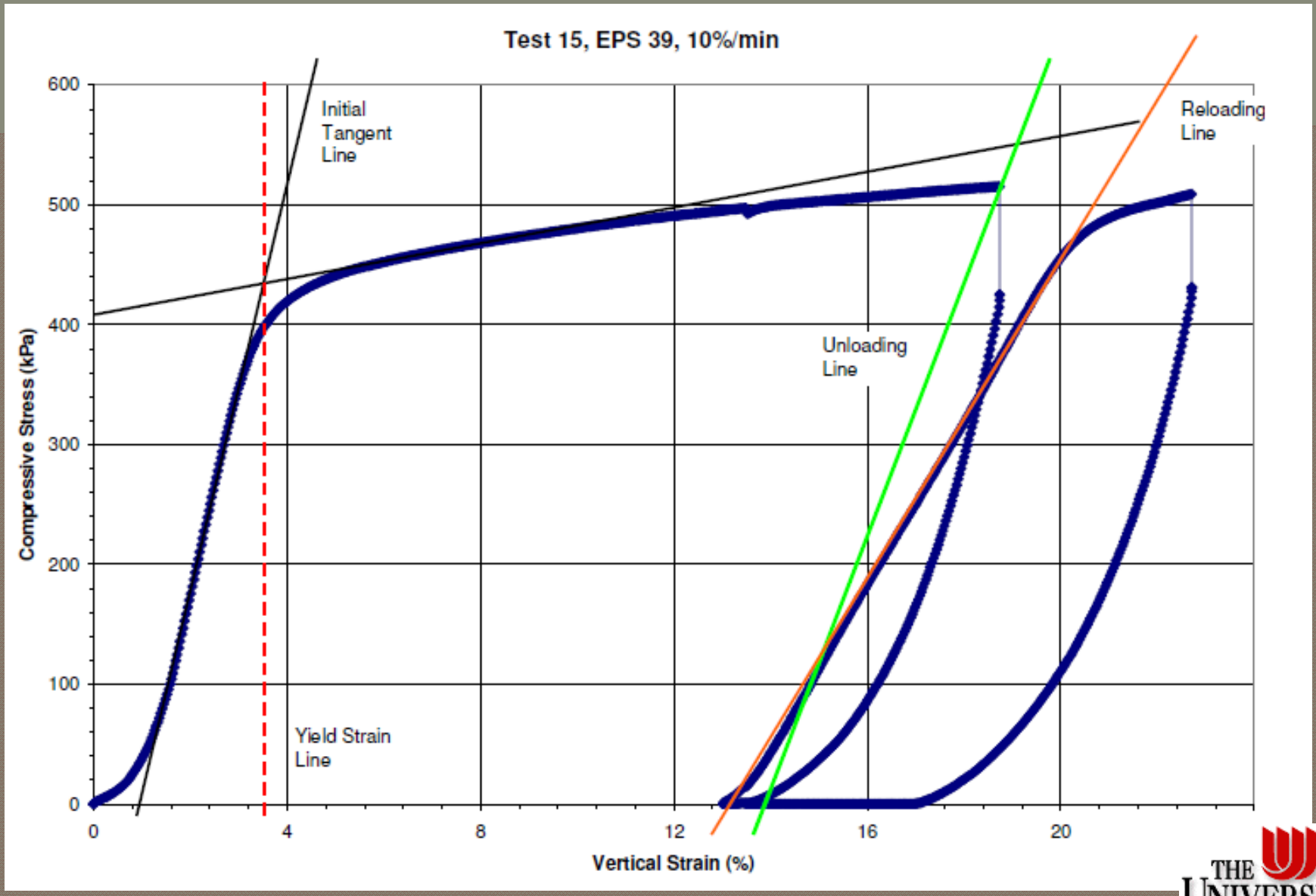
Geofoam Properties Under Monotonic Loading



Lingwall and Bartlett (2010)

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Block Compression Tests

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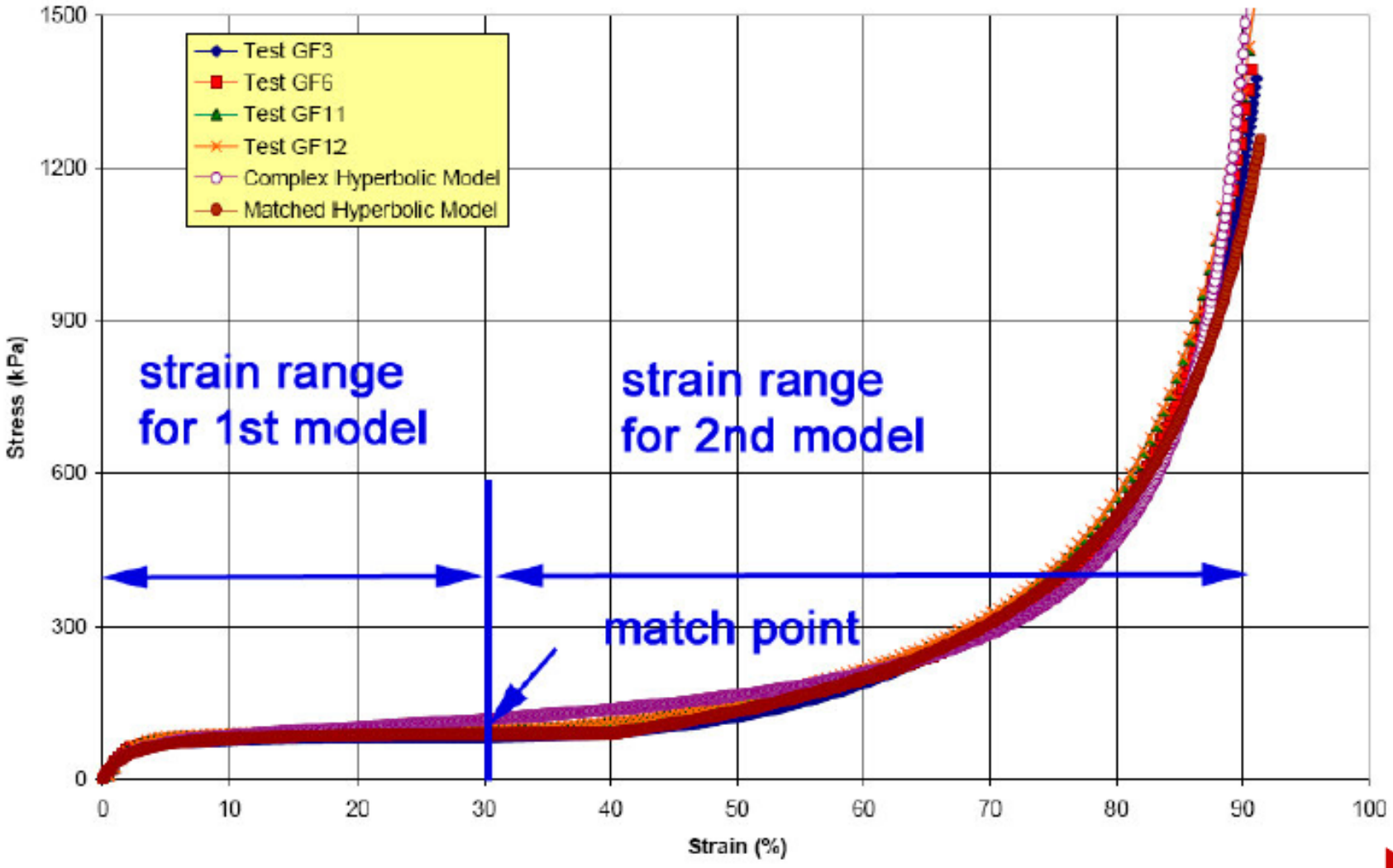
Geofoam Large Strain Behavior



Typical Stress – Strain Curve for EPS (Lingwall and Bartlett, 2010)

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Geofoam Advantages

- Light weight material
  - Reduces static and seismic loads to walls, buried structures
  - Improves slope stability (static & dynamic)
  - Reduces consolidation settlement on soft ground
- Controlled Compression (Compression Inclusion)
  - Can undergo elastic and plastic deformation but maintains general shape
  - Reduces loads to buried structures by compression and mobilization of soil's shear strength in the surrounding area

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Topics

- Introduction to EPS
- Seismic Hazards
- Pipeline Protection Strategies
- Development of EPS Light-weight Cover
- Test Results
- Field Application

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Sources of Permanent Ground Deformation

- Tectonic Faulting
- Subsidence and Settlement
- Landsliding and Other Types of Mass Movement
- Liquefaction and Lateral Spread

Light-weight cover system can offer a potential solution to many of these types of ground displacement, but more development is need.

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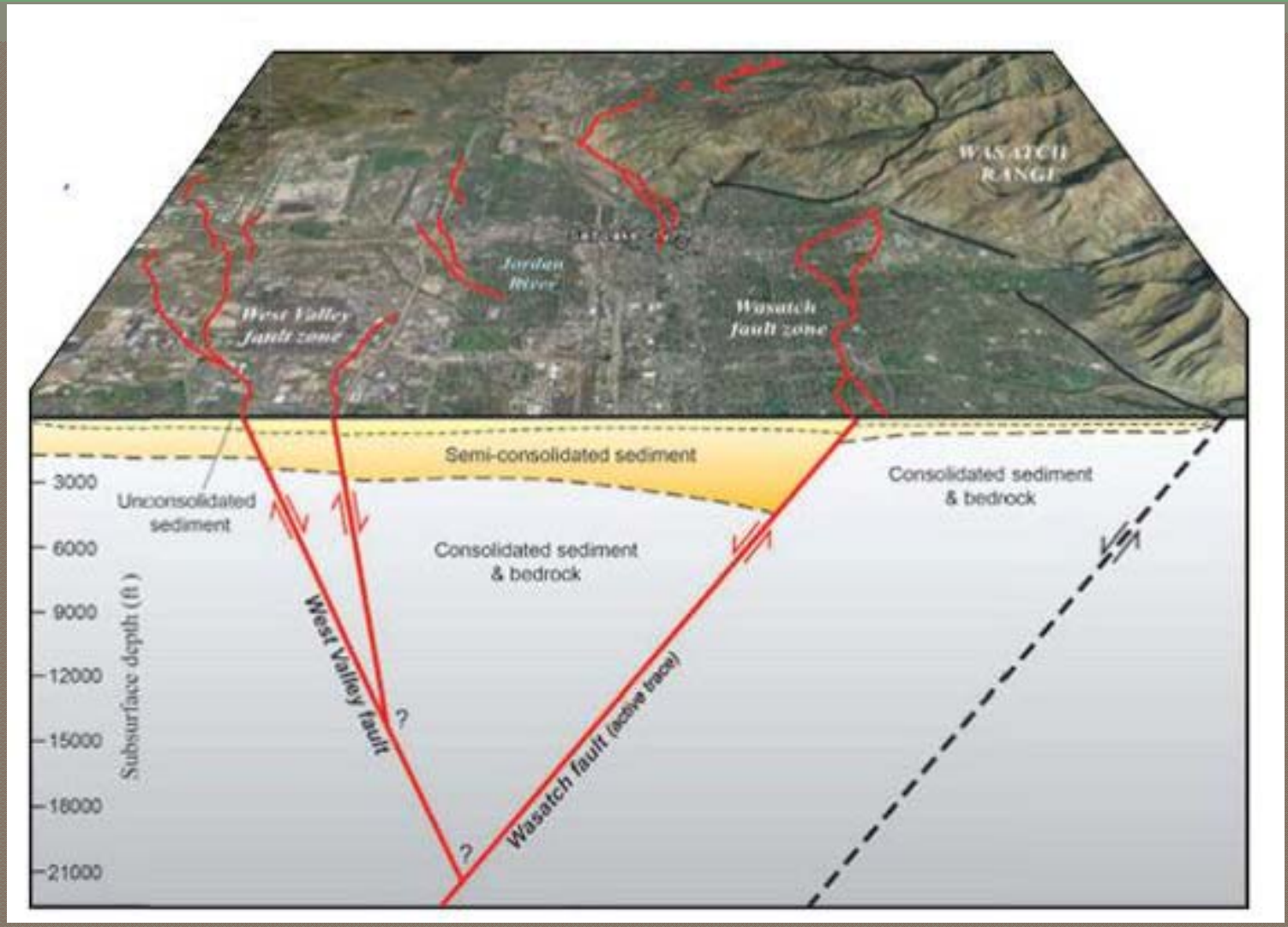
Wasatch Fault – Salt Lake City Segment



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Wasatch Fault at Little Cottonwood Canyon

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Fault-Induced Pipeline Rupture

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Topics

- Introduction to EPS
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Pipeline Protection Strategies

- Mechanical Devices
  - Expensive
  - Cannot easily remediate existing problem
  - Proprietary
  - Tend to induce extra axial forces on pipeline

http://www.wateronline.com/product.mvc

Pipelines (Protection for Strike Slip Faults)

Alaskan Pipeline – Strike Slip Fault

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Pipelines (Protection for Normal and Reverse Faults)

Shallow Burial – Normal Faulting

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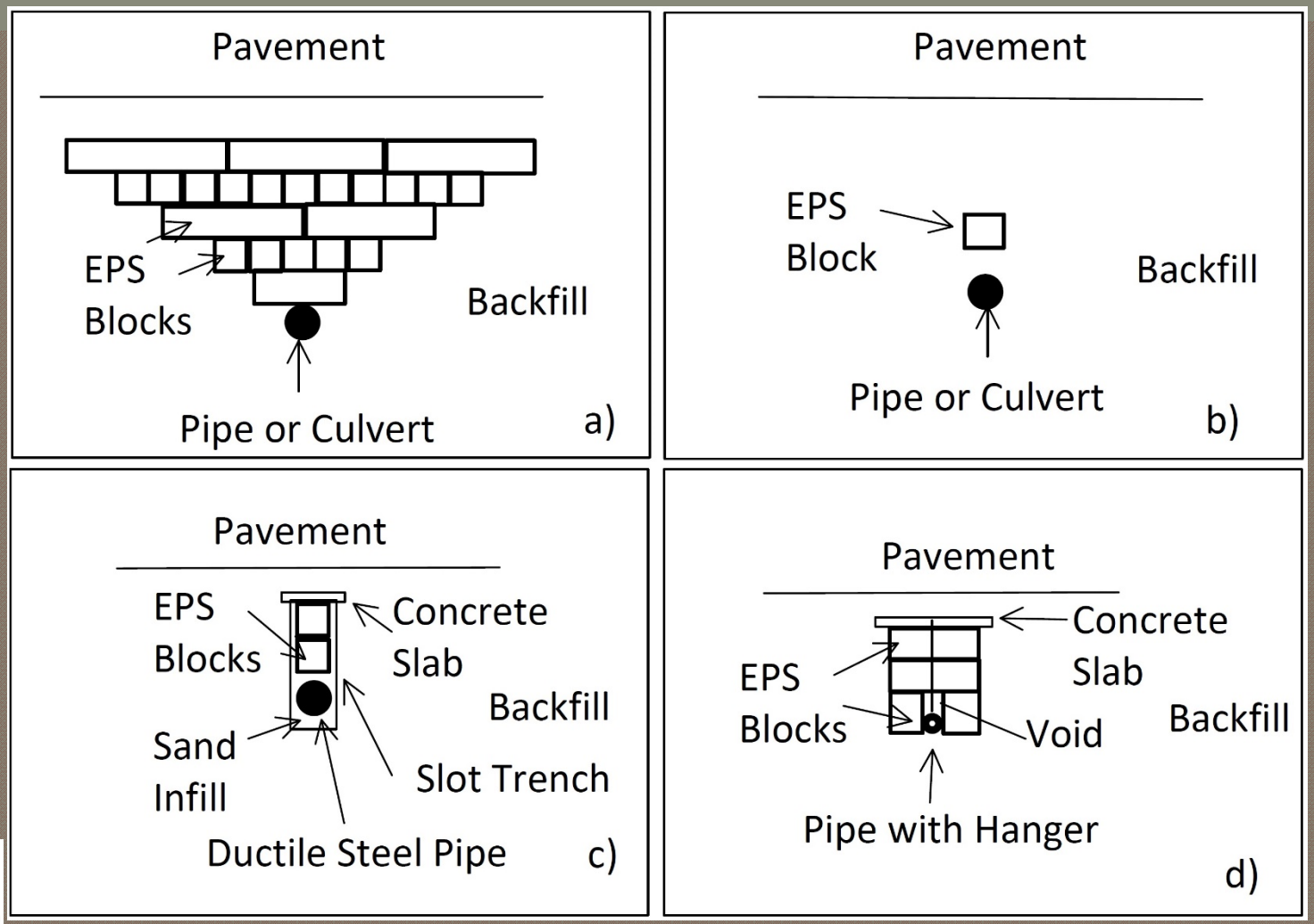
Common EPS Protection Strategies



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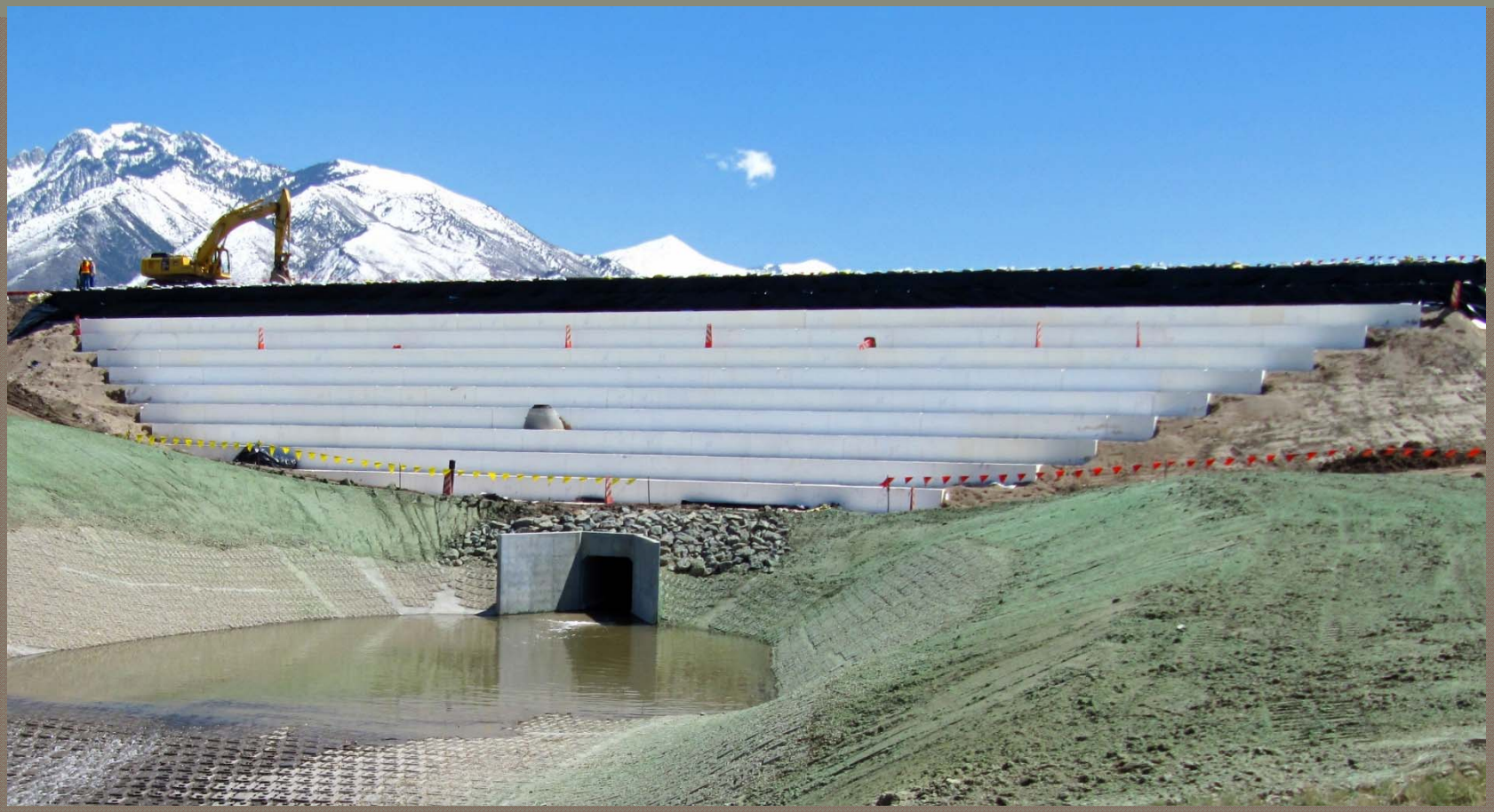
Light-weight Cover



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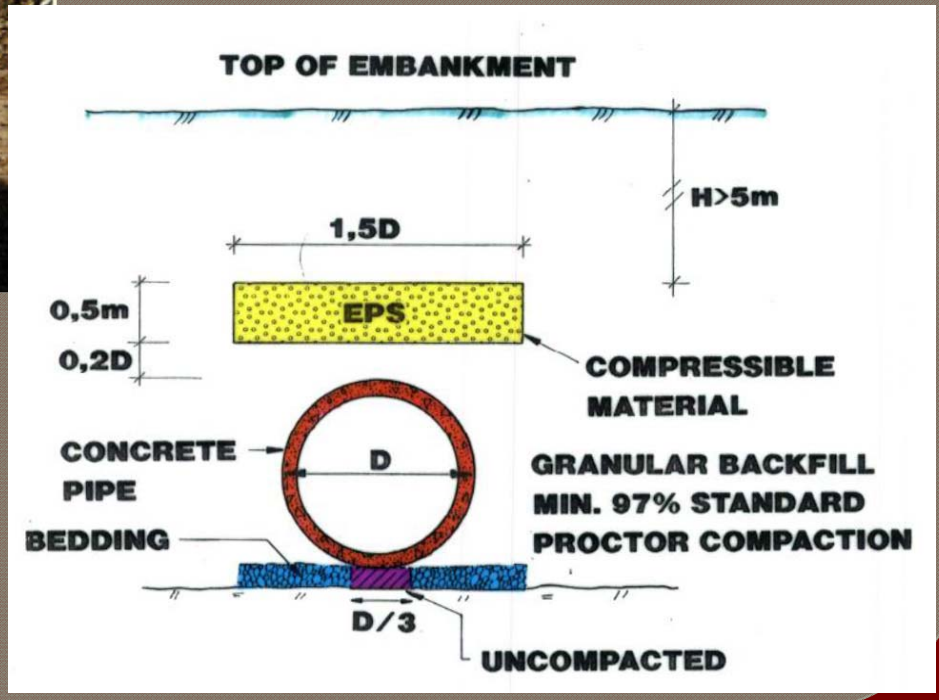
UTA Front Runner System, Corner Canyon, Draper, Utah (photo courtesy of ACH Foam)

Compressible Inclusion – Imperfect Trench Method

Eidanger, Norway 1988 (photo courtsey of Norwegian Public Roads Administation).



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Slot Trench Cover System

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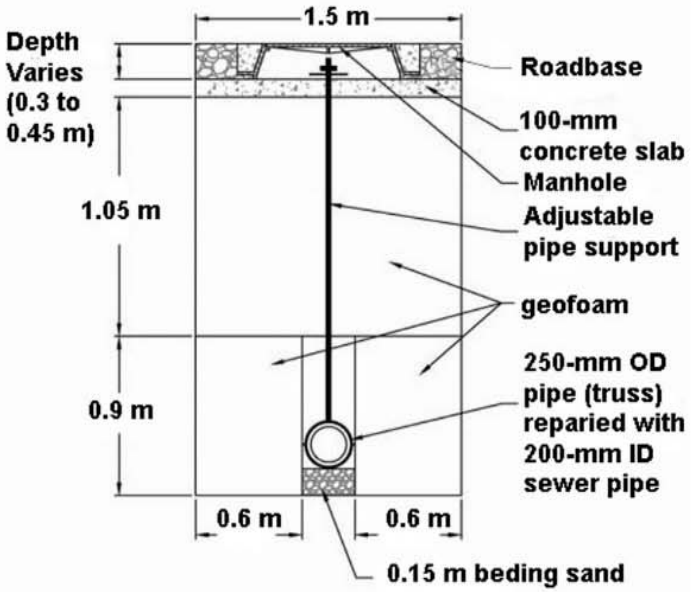
Salt Lake City, Utah

Post and Beam Cover System



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Brian Head Ski Resort, Cedar City, Utah

Topics

- Introduction to EPS
- Seismic Hazards
- Pipeline Protection Strategies
- Development of EPS Slot Trench Cover
- Test Results
- Field Application

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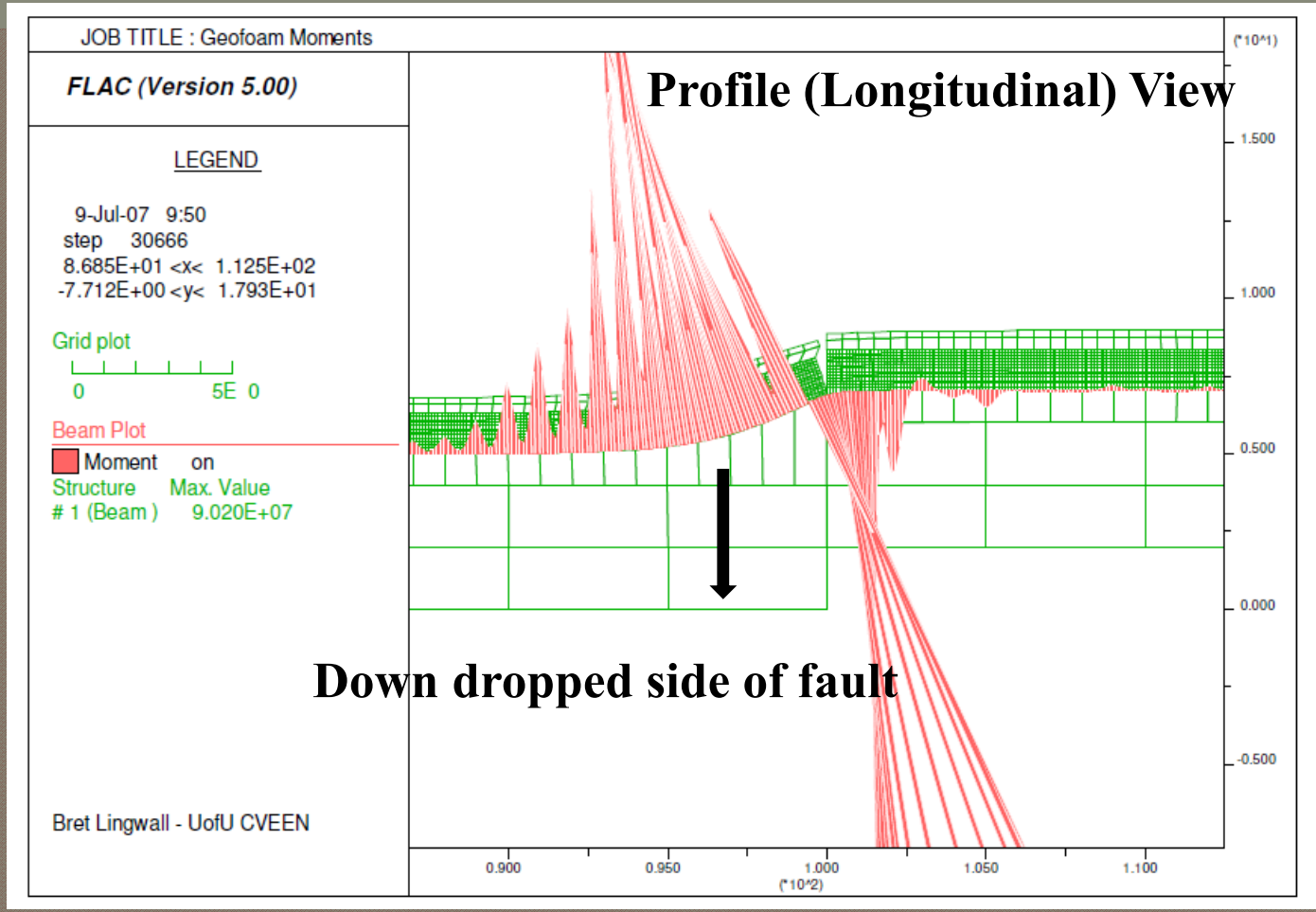
Pipelines (Light-weight Cover Over Normal Faults)



Bending Moments in Pipe from 2 m offset

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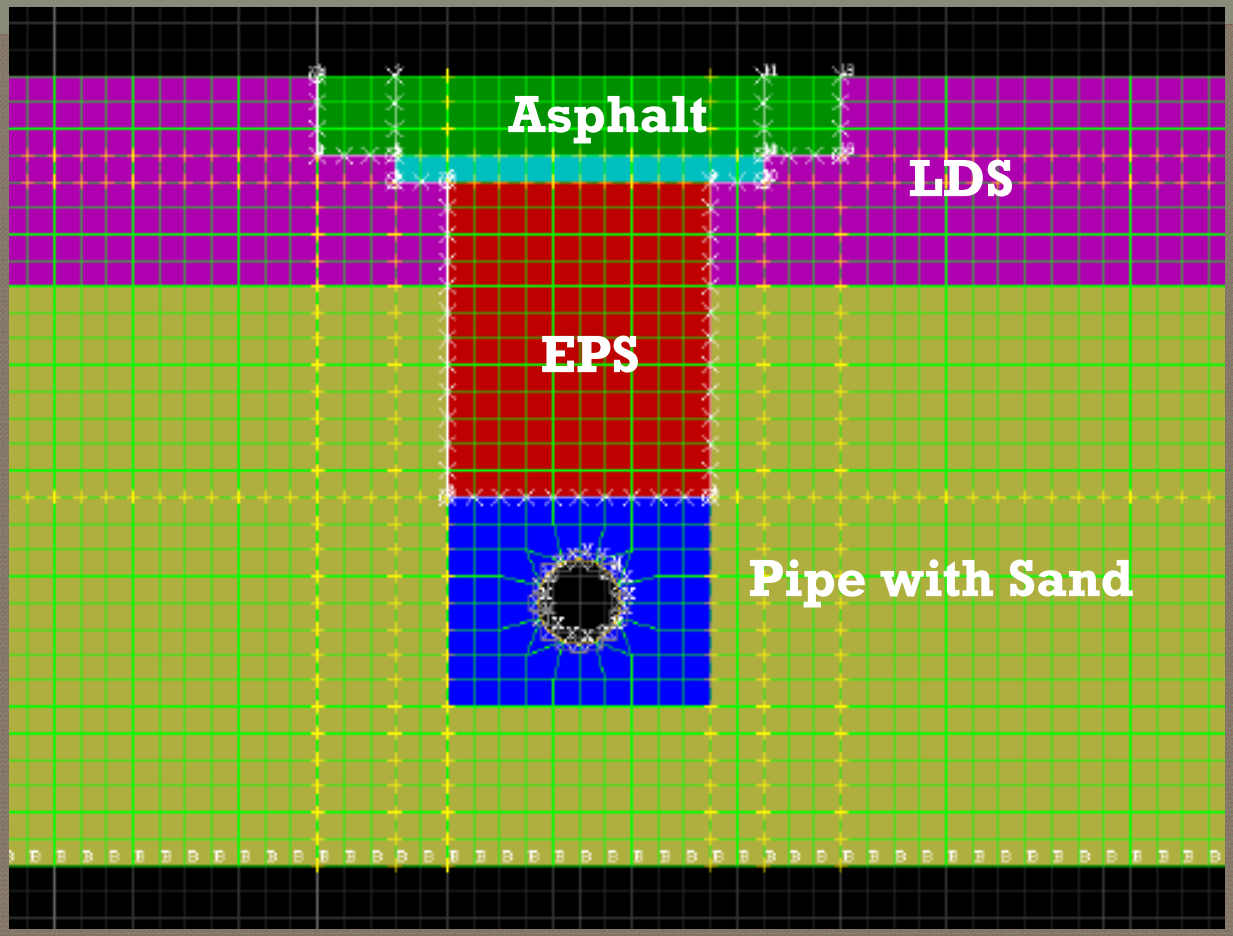
Pipelines (Light-weight Cover Over Normal Faults)



Lightweight-Cover System
(X-sectional View)

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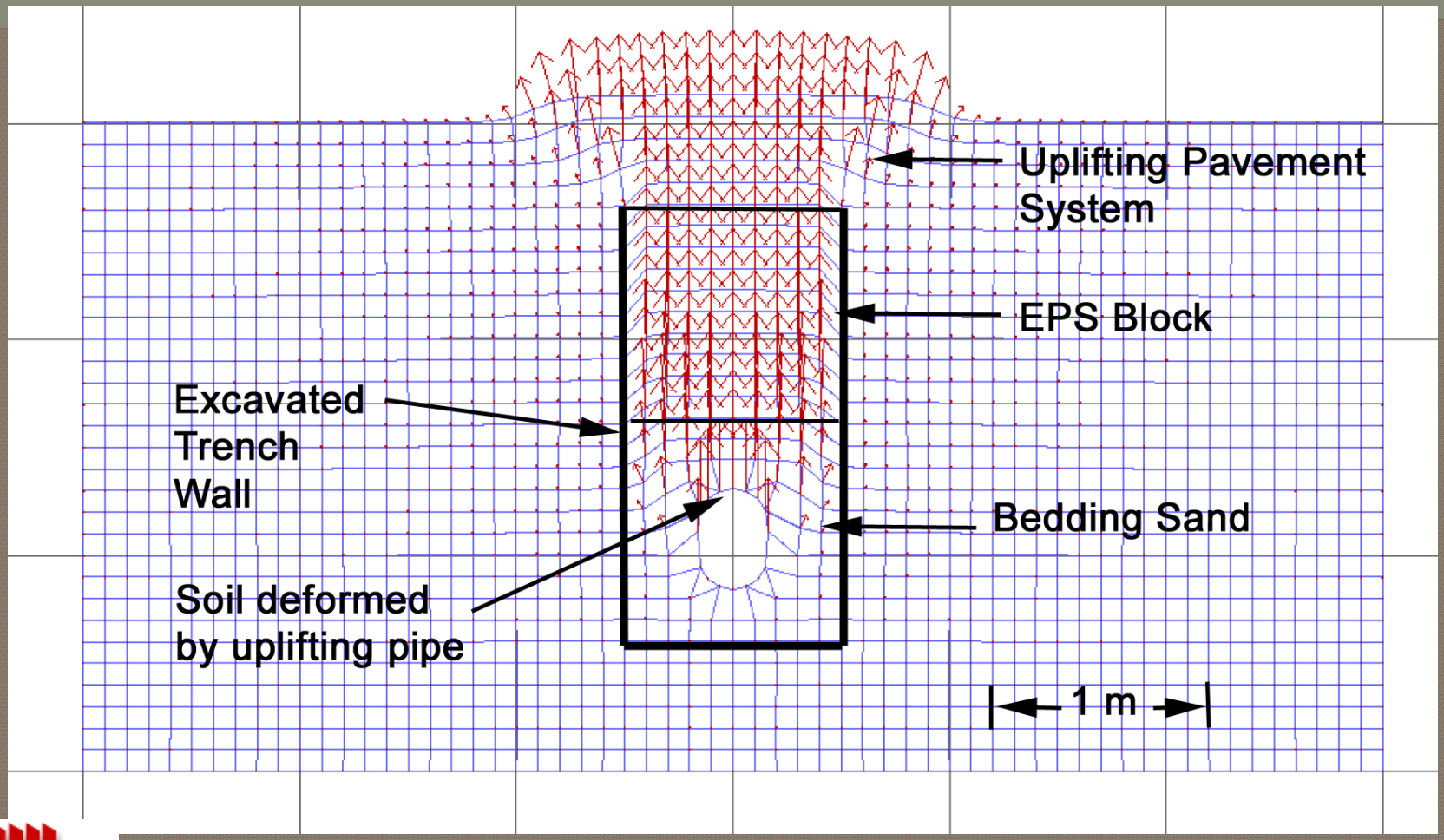
Pipelines (Light-weight Cover Over Normal Faults)



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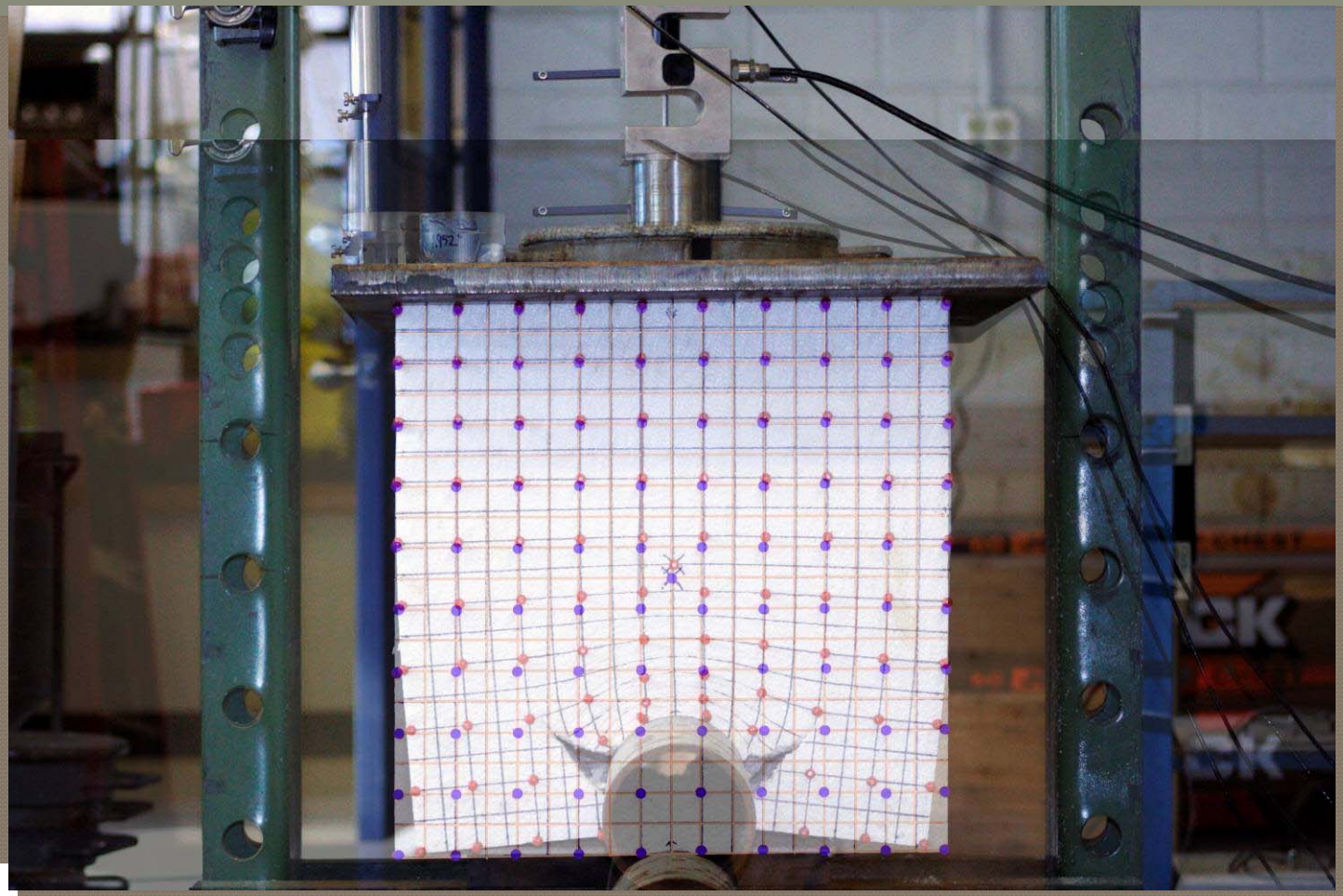
Displacement Vectors During Failure

Geofoam Pipe Interaction



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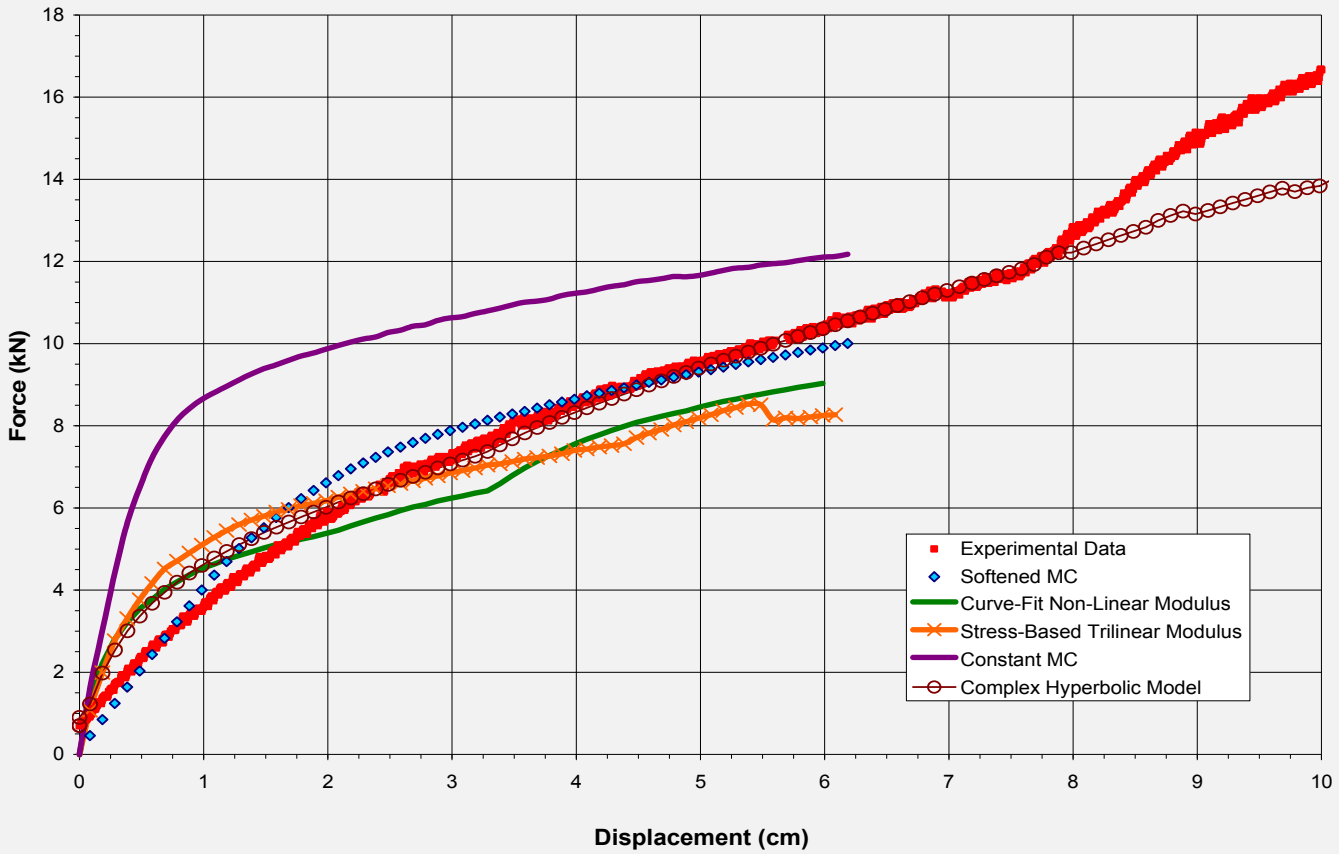
Geofoam Pipe Interaction Modeling



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Construction of Uplift Tests

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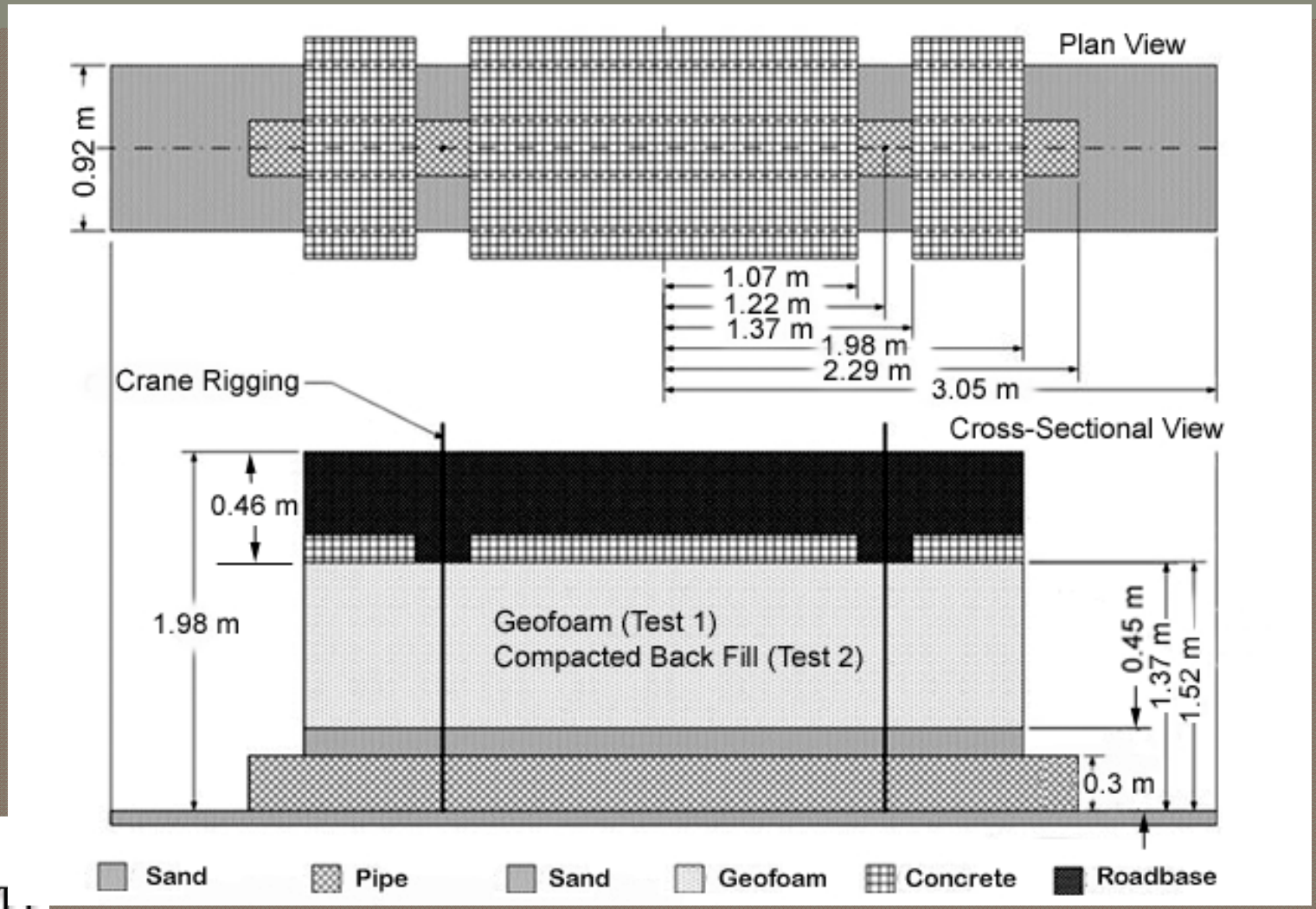
Lift-up Test Layout



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Vertical Uplift Tests

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Topics

- Introduction to EPS
- Seismic Hazards
- Pipeline Protection Strategies
- Development of EPS Light-weight Cover
- Test Results
- Field Application

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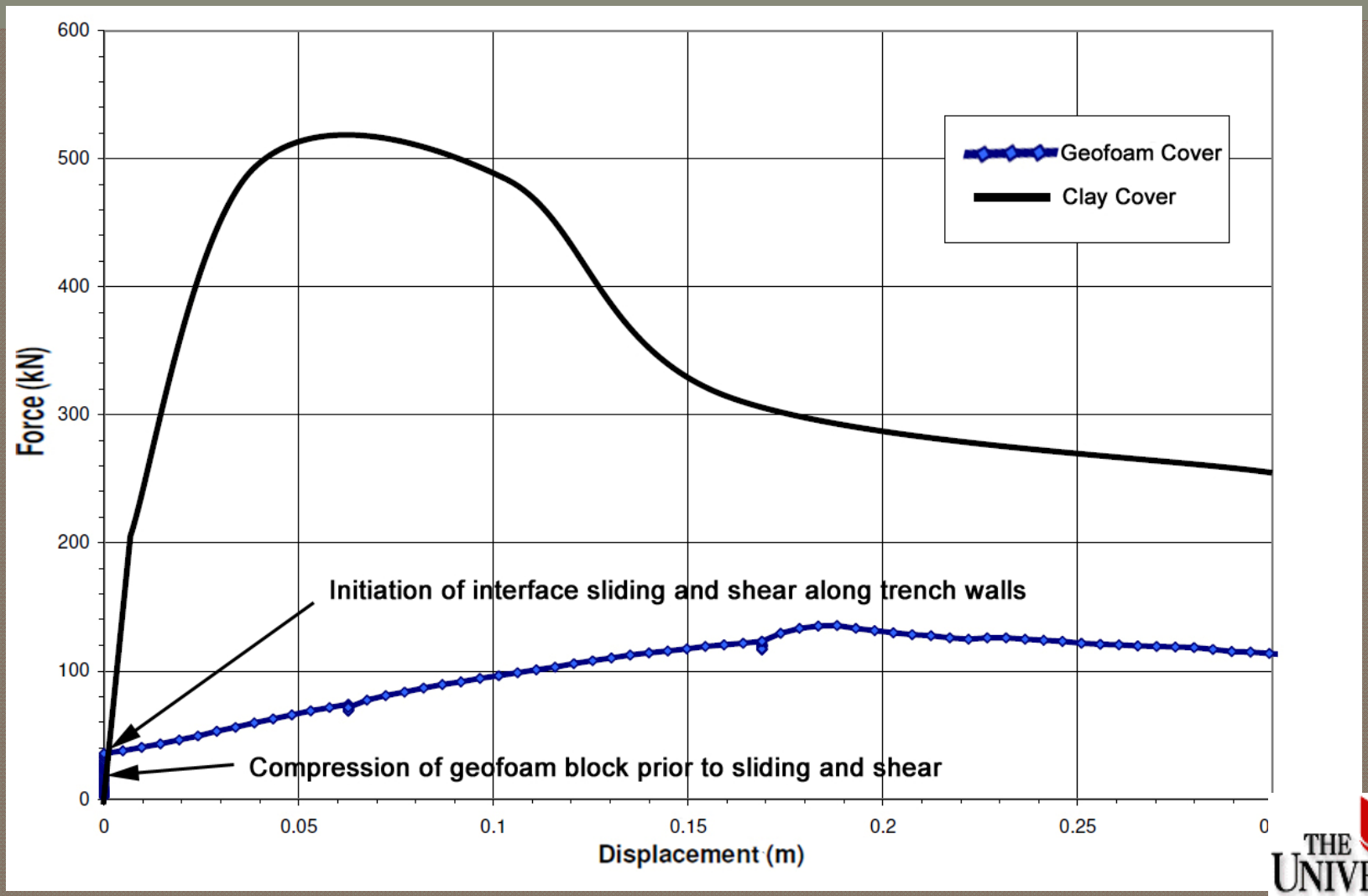
Force-Displacement Curves from Uplift Tests



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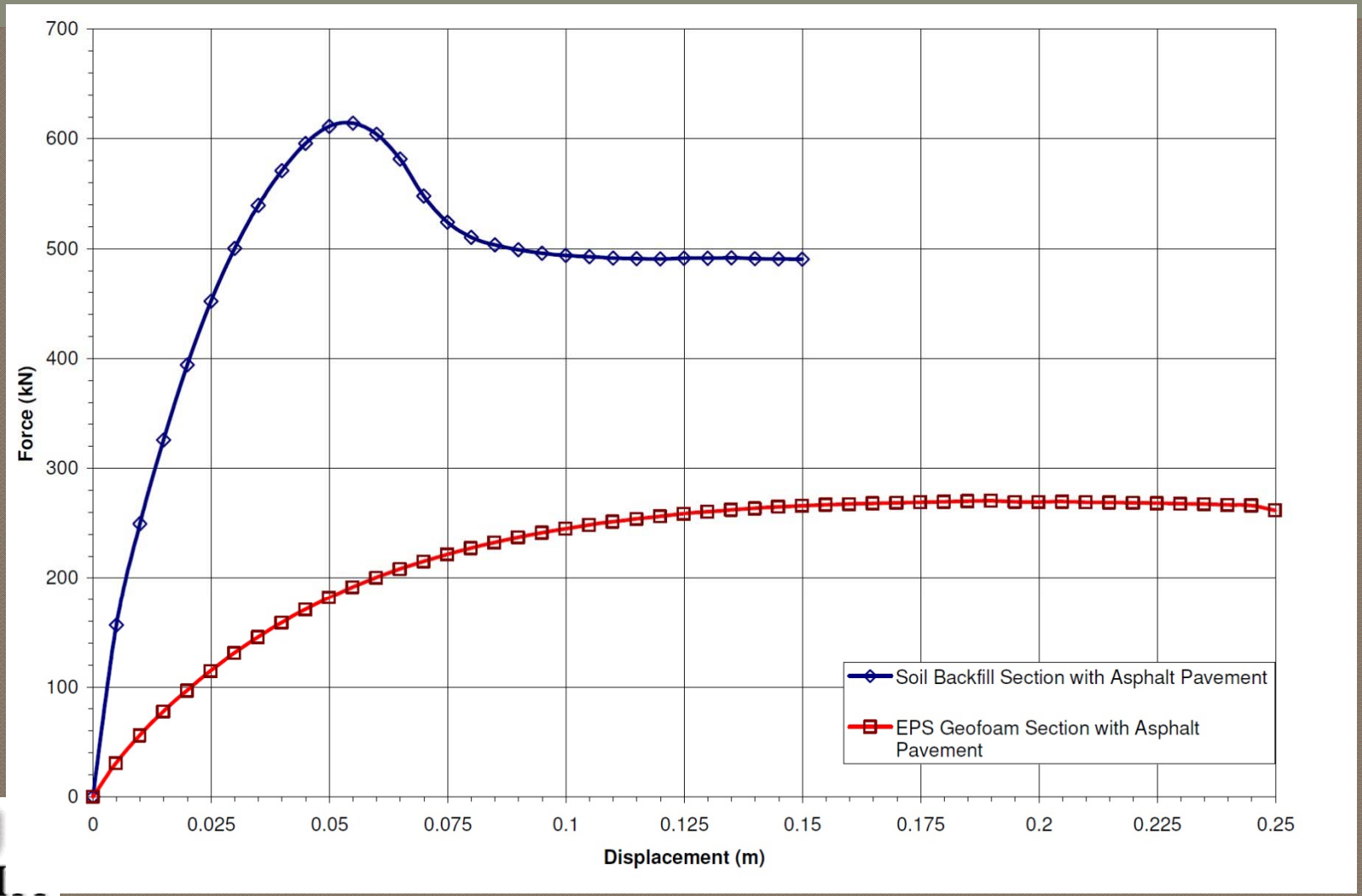
Results of Numerical Modeling of Cover with Asphalt



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Topics

- Introduction to EPS
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500 South Fault Crossing – Salt Lake City, Utah

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Conclusions

- Light weight EPS cover systems can be effective in preventing rupture of high strength steel-pipelines undergoing vertical offset from permanent ground displacement.
- The EPS light-weight cover strategy presumes that surface damage caused by uplift of the cover is acceptable.
- Light weight cover systems can also be used to accommodate horizontal movement.

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Sponsors

Questar Gas Corporation, Salt Lake City, Utah

Bechtel Corporation, San Francisco, California

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For More Information

http://www.civil.utah.edu/~bartlett/Geofoam/

Technical Session 6 – Emergency Management and Public Safety

Moderator: Bob Carey, Utah Division of Emergency Management

Scientific Response to the 2008 M6 Wells, Nevada Earthquake: *Craig dePolo, Nevada Bureau of Mines and Geology*

Emergency Response – 2008 M6 Wells, Nevada Earthquake: *Rich Harvey, Deputy State Forester (retired), Nevada Division of Forestry* (PowerPoint only)

Engineering Considerations – 2008 M6 Wells, Nevada Earthquake: *Barry Welliver, Structural Engineers Association of Utah*

The Recovery of Wells, Nevada from the 2008 M6 Earthquake: *Craig dePolo, Nevada Bureau of Mines and Geology*

Acceptable Risk for Surface-Fault Rupture in the Basin and Range Province: *Roy Shlemon, R.J. Shlemon & Associates*

Building Policy Considerations in Seismically Vulnerable Areas of the Basin and Range Province: *Ron Lynn, Clark County, Nevada Department of Development Service*

Modernizing the 1972 California Alquist-Priolo Fault Zoning Act for the Performance-Based Millennium: *Eldon Gath, Earth Consultants International*

SCIENTIFIC RESPONSE TO THE 2008 M6 WELLS, NEVADA EARTHQUAKE

Craig M. dePolo
Nevada Bureau of Mines and Geology, MS-178, University of Nevada, Reno,
1664 N. Virginia Street, Reno, Nevada, 89557
cdepolo@unr.edu

Scientists from the Nevada Seismological Laboratory (NSL), the University of Utah Seismograph Stations (UUSS), the United States Geological Survey (USGS), the Nevada Bureau of Mines and Geology (NBMG), the Utah Geological Survey (UGS), the University of Nevada, Reno Center for Neotectonic Studies (CNS), and the University of California, Berkeley responded to the February 21, 2008 Mw 6.0 Wells, Nevada earthquake. A temporary seismic array was deployed by NSL, UUSS, and the USGS and telemetered to NSL at the University of Nevada, Reno. Stations were installed by dedicated technicians and scientists with snow transportation assistance from the local power company and Nevada Department of Transportation. Investigations into the surface effects were initiated by the UGS, NBMG, and CNS, but were challenging because of the snow-covered landscape and continued snowy conditions.

Many studies of the earthquake were conducted in laboratories, including detailed earthquake source studies from seismic waves, strong ground motion summaries, deformation measured with InSAR and GPS data, infrasonic waves, coulomb stress changes on local faults, regional structural setting, bedrock geology, Quaternary fault setting, and gravity and magnetic geophysical setting. These studies provided a tremendous amount of background and perspective information for the earthquake. There was a remarkable amount of additional information available or that could be found to document earthquake effects. For example, a claim by many locals that the shaking went on for 40 seconds was verified by examining security footage from a local grocery store; the liquor aisle camera showed ground motion the clearest, including the long basin response that extended the shaking. Follow-up field studies measured temperatures in local geothermal springs, and shallow shear-wave velocities were measured in areas where damage occurred.

The scientific response was mostly coordinated in the office or the field by the main scientists working on the earthquake. The UGS modified a pre-developed technical information clearinghouse website for the earthquake until the NBMG could establish a clearinghouse website, where the clearinghouse was then transferred in a wonderfully coordinated effort.

One of the most interesting small projects I was engaged in was noting the direction objects were thrown, toppled, or slid during the earthquake. During the initial investigation of the damage, I noted there were skid marks from equipment moved by the earthquake in the sawdust of the high school wood shop. I requested that the skid marks be preserved until I could return to measure them a week later. Although the shop was cleaned out by the time I returned, a halo of sawdust was left around each machine so the direction they slid could be measured. This inspired me to look for other signs of the movement during the strongest part of the earthquake, such as which direction chimneys fell or how wall orientation affected whether books fell or remained on bookcase shelves.

Scientists need to accurately measure and describe earthquake events and capture as much perishable data as possible to improve seismic-hazard analyses and our general understanding of the earthquake threat. Some targets, like defining the main earthquake and aftershock sequence, are clear from the outset. Other information may not have obvious value at the time, but can be used for inquiries posed in the future; open-mindedness and inclusiveness are useful traits for documenting earthquakes. Papers on the results of scientific investigations into the 2008 Wells earthquake can be found in the compendium volume for the earthquake online at: http://www.nbmg.unr.edu/freedownloads/sp/sp036/.

The following is a PDF version of the author's PowerPoint presentation.

Scientific Response to the 2008 M6 Wells, Nevada Earthquake

Craig M. dePolo

Nevada Bureau of Mines and Geology

The 2008 Wells Earthquake

- February 21 at 6:16 a.m. PST
- Moment Magnitude: 6.0
- Normal fault: strike N40°E, dip 55°SE
- Rupture: ~8 km long, max. slip 0.86-1.03 m
  No surface rupture found
- Long shaking duration reported: 40 secs
- Basin surface downwarped as much as 15 cm

Seismologists Mobilized to get Seismometers Installed Locally

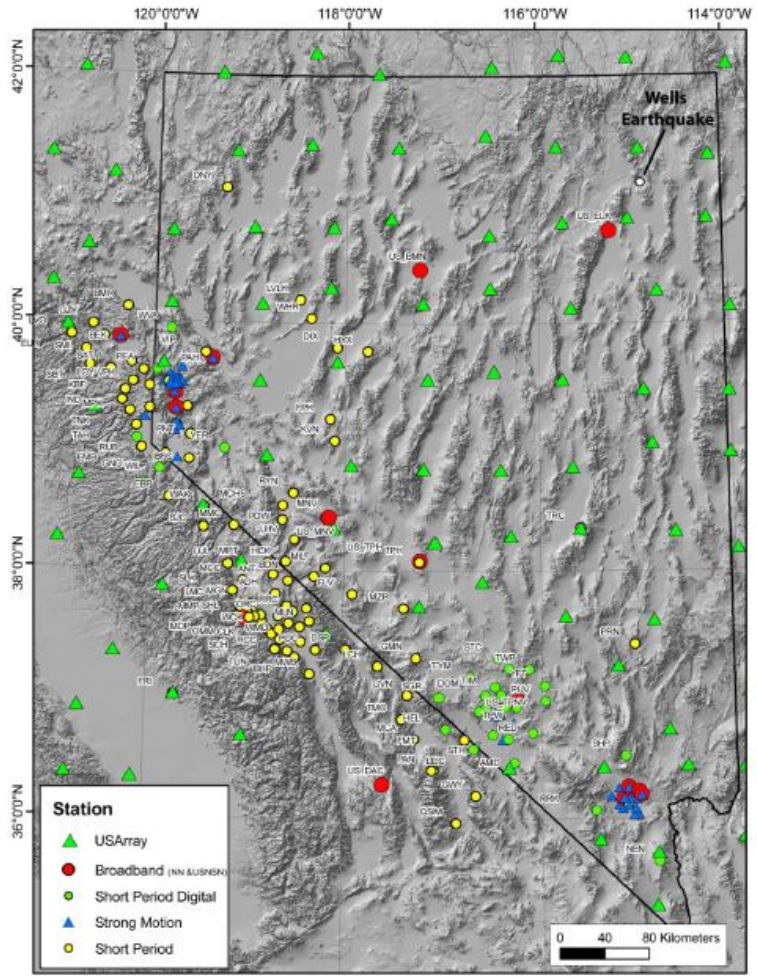


Figure 1. Regional monitoring stations in Nevada and eastern California including EarthScope USArray and USGS ANSS (USNSN) broadband stations. Also shown is the location of the Wells earthquake.

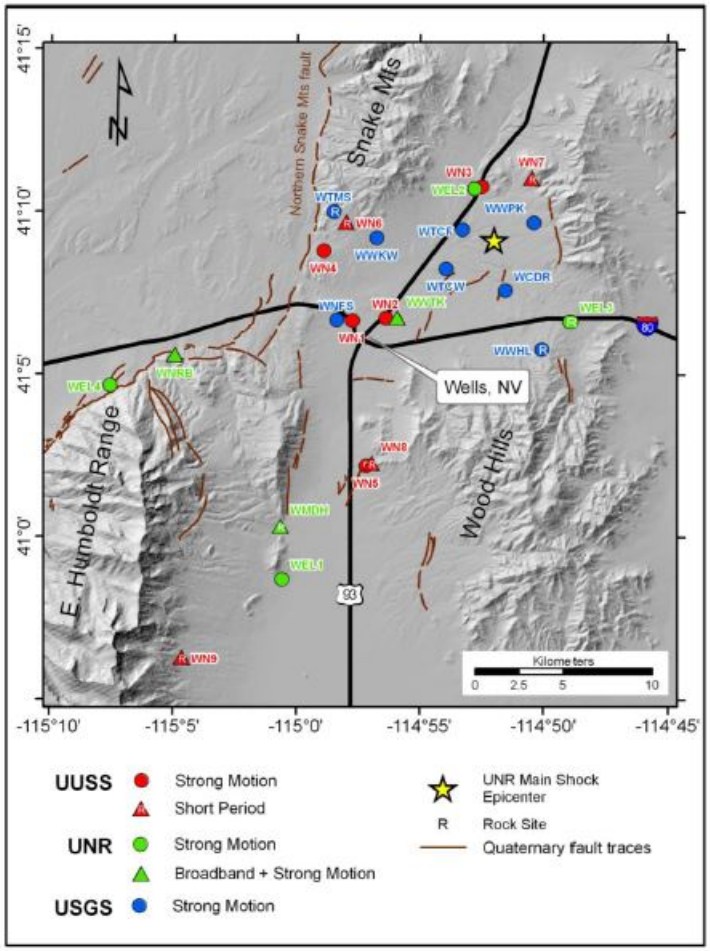


Figure 2. Map showing the distribution of temporary seismic stations deployed following the 2008 M_W 6.0 Wells earthquake (table 1). Three of the 27 stations are located southwest of the map area and are therefore not shown. Rock sites, which are indicated by an "R," are defined as sites for which the estimated bedrock depth is less than 5 m (Boore and Joyner, 1997). Town Creek Flat (TCF) basin is the broad lowland northeast of Wells that includes the mainshock and most of the portable deployment.

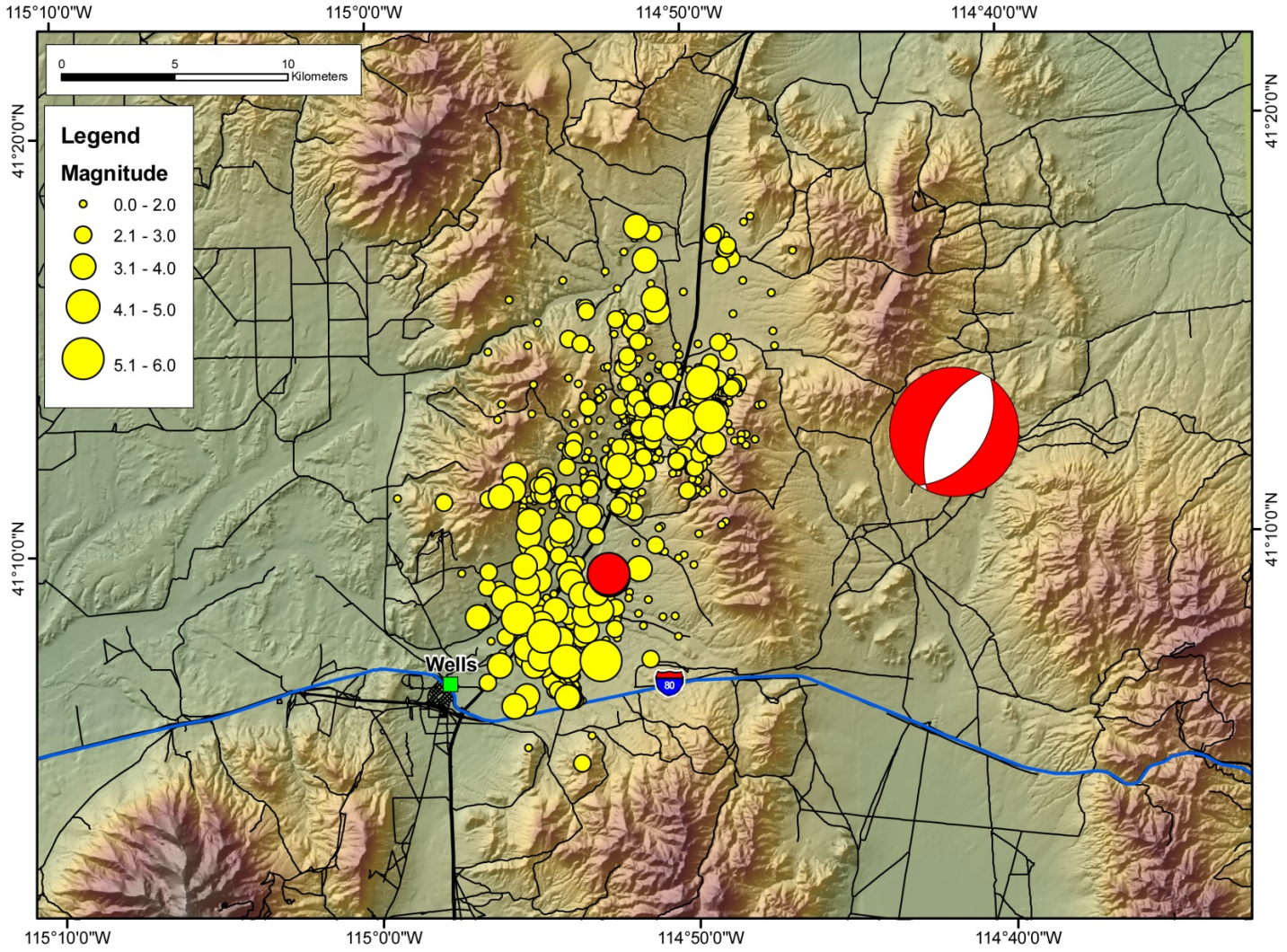
K. Smith, J. Pechmann, M. Meremonte, K. Pankow (2011)

Local Seismometer Telemetry

Figure 3. Map of telemetry paths for USGS RT130 instruments to DoIT relay Turner Station (map using software application Google Earth http://earth.google.com/).

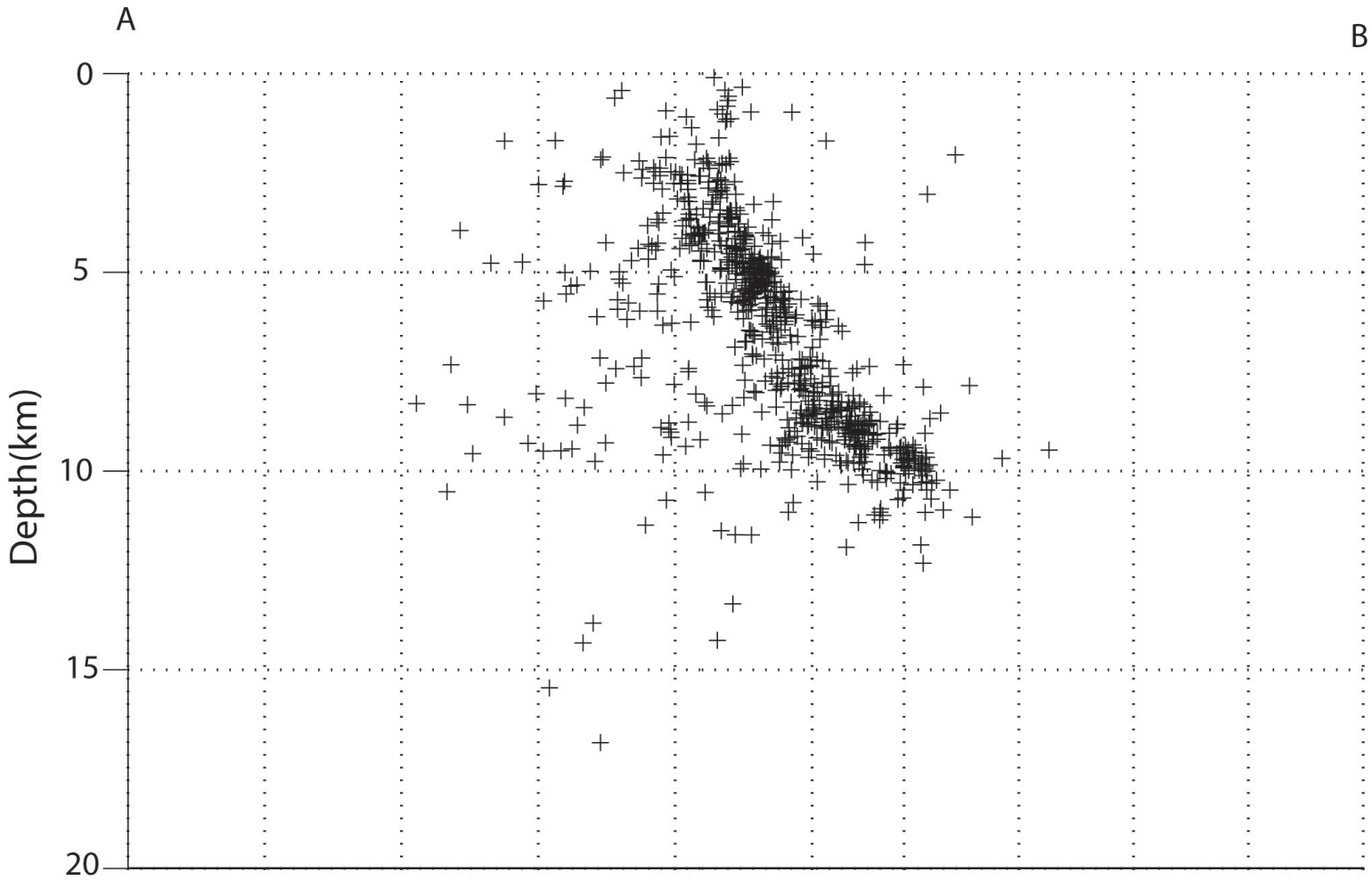
K. Smith, J. Pechmann, M. Meremonte, K. Pankow (2011)

2008 Wells Earthquake



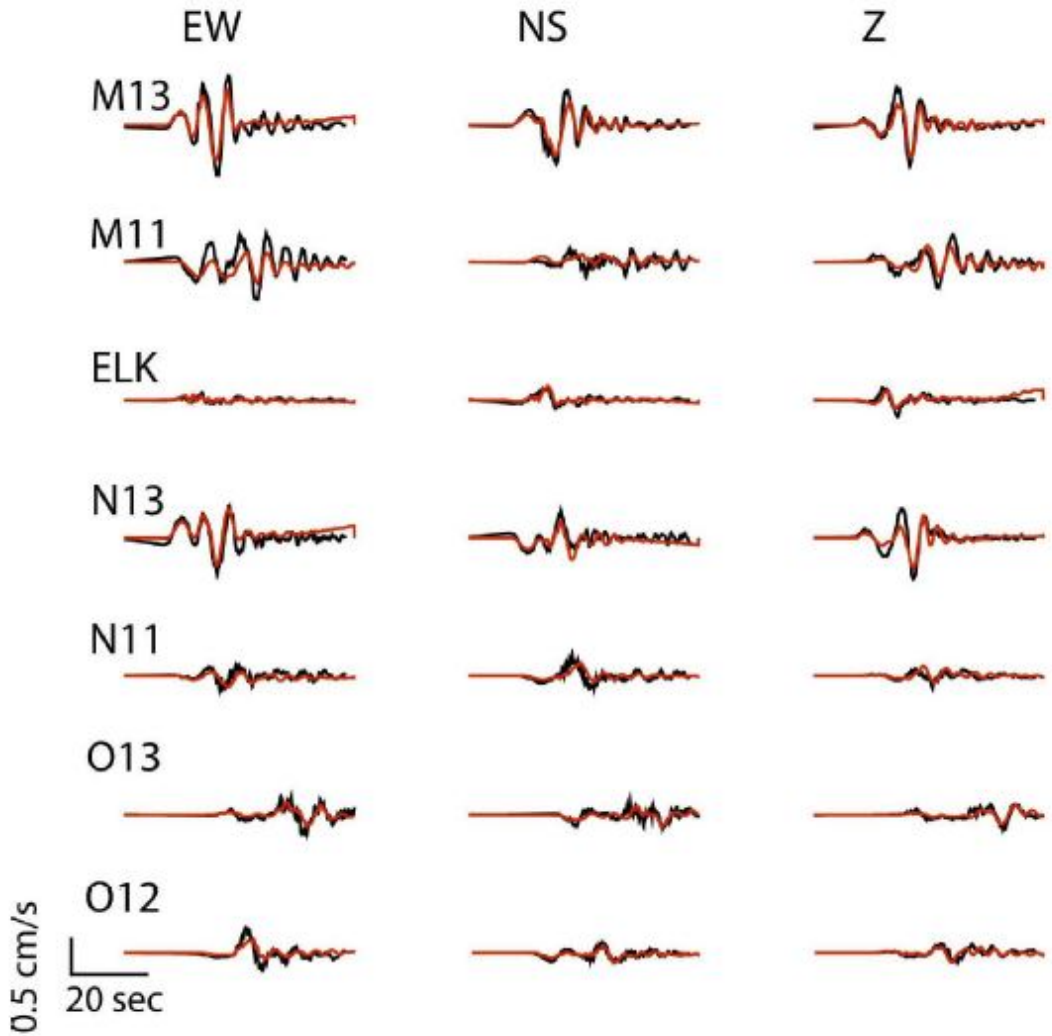
Ken Smith, UNR Nevada Seismological Laboratory

Cross Section of Seismicity



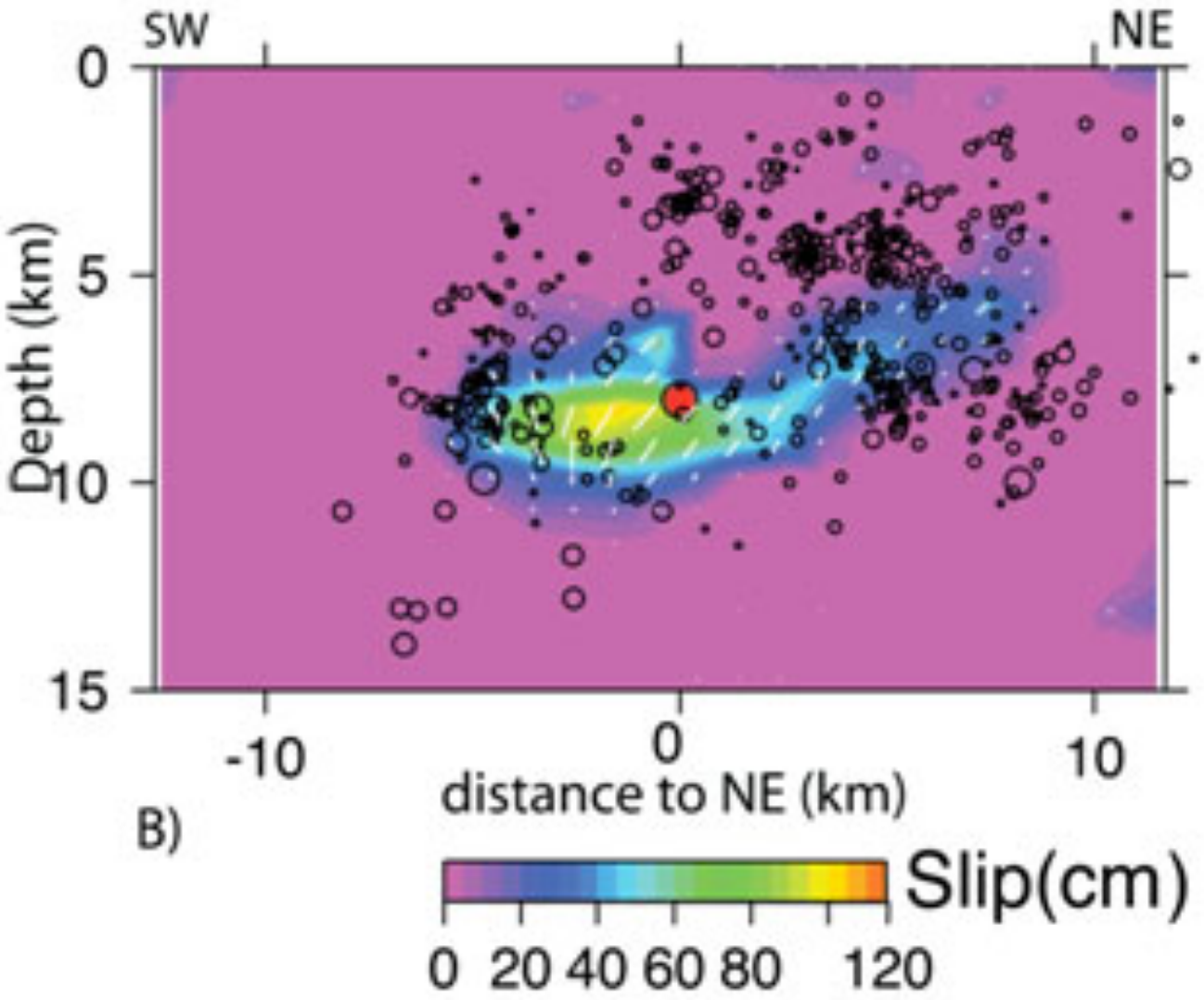
K. Smith, J. Pechmann, M. Meremonte, K. Pankow (2011)

Preliminary Finite-Source Study



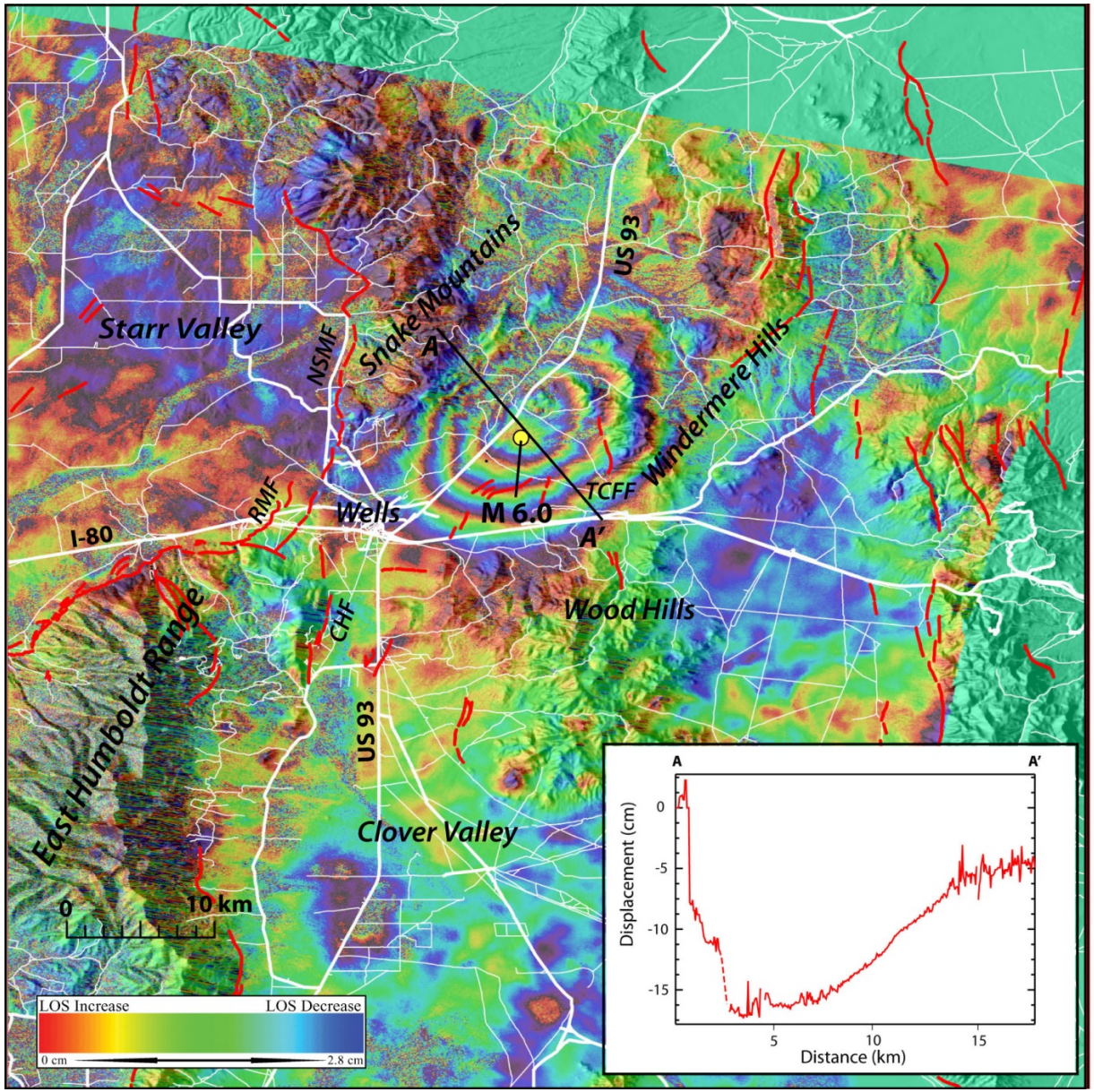
D. Dreger, S. Ford, I. Ryder (2011)

Source Model of Displacement



D. Dreger, S. Ford, I. Ryder (2011)

Interferometric Synthetic Aperture



J. Bell (2011)

Foreshocks to Main Event

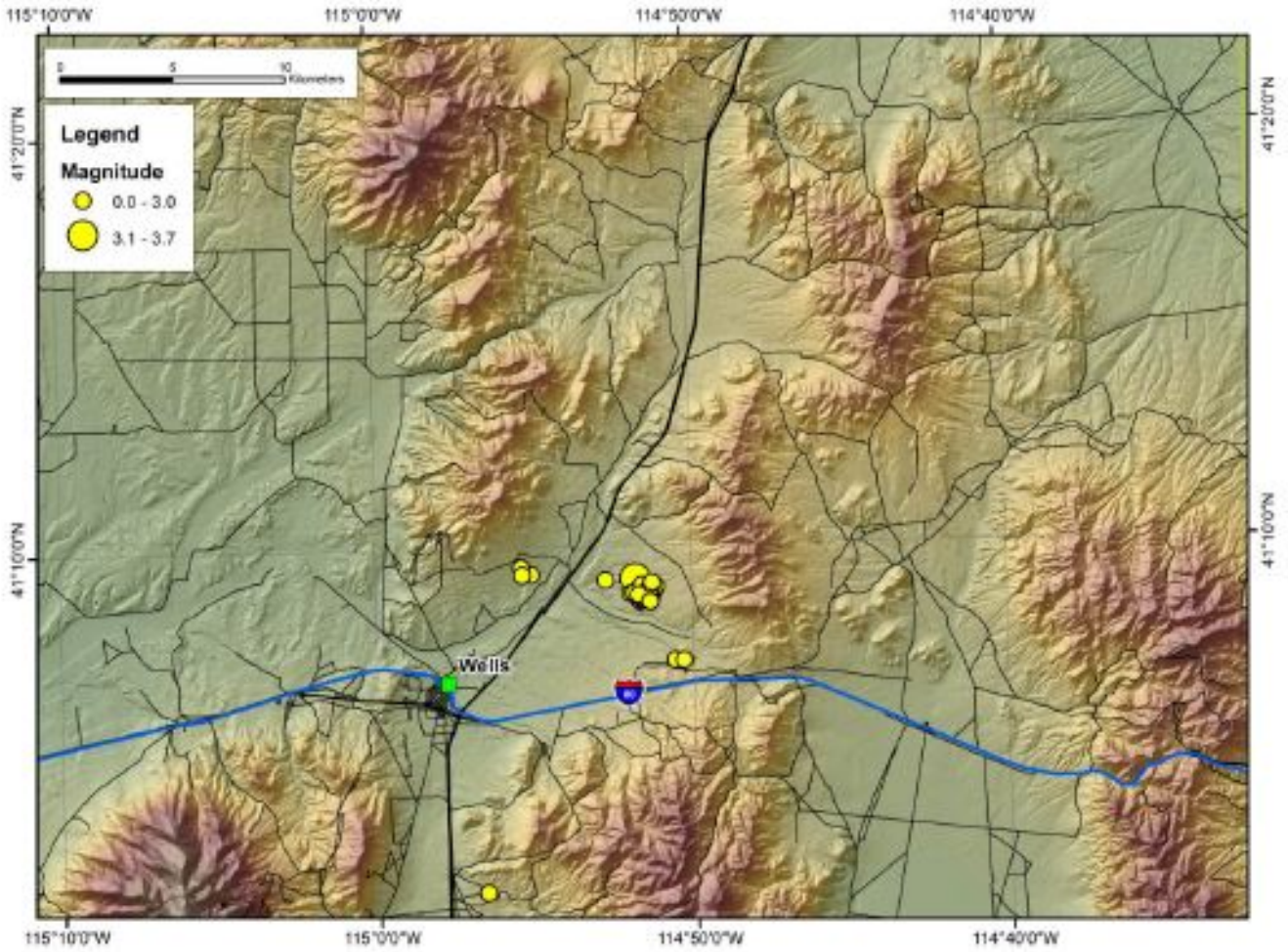
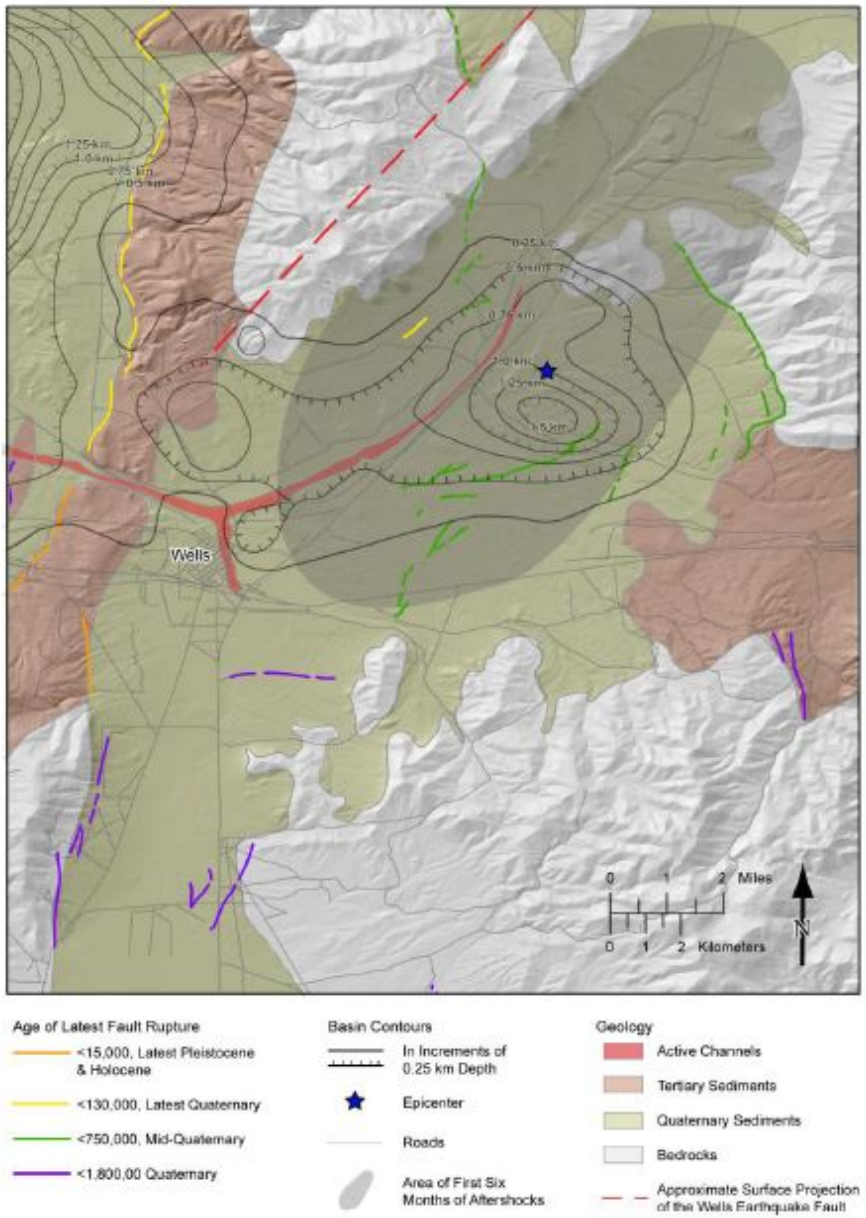


Figure 5. HypoDD relocations of activity recorded in the TCF area from January 2000 through February 21, 2008. All events shown occurred before February 28, 2007.

K. Smith, J. Pechmann, M. Meremonte, K. Pankow (2011)

Geologic Setting



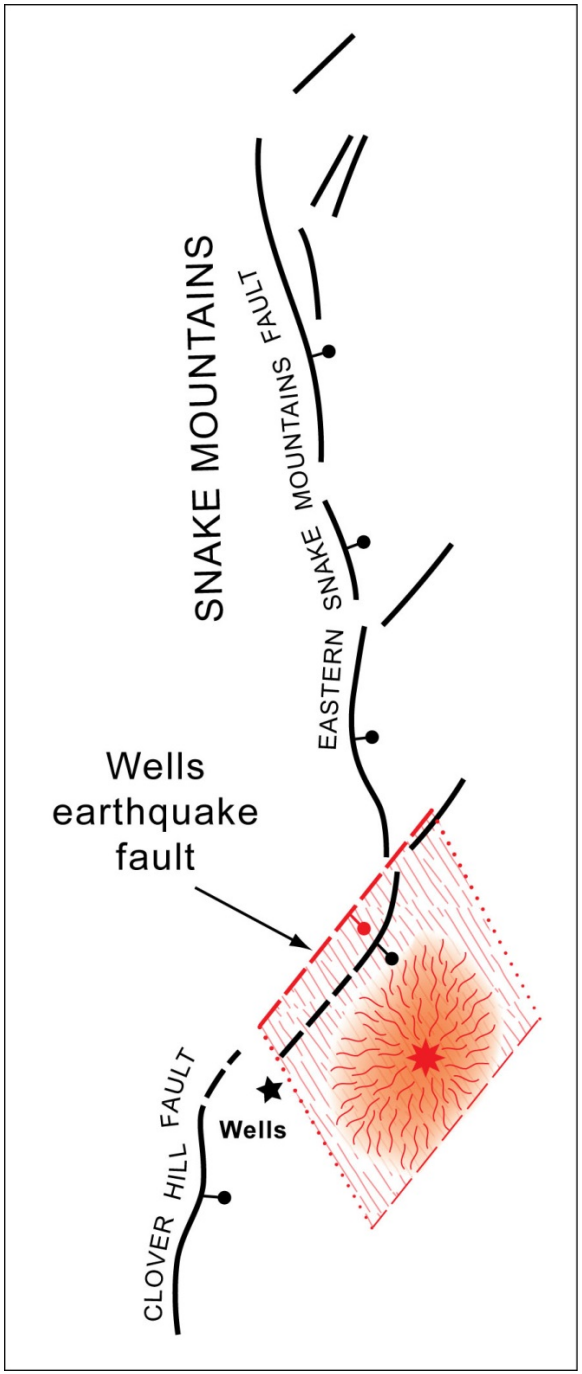
Geology: C. Henry, J. Colgan (2011)
C. Thorman, W. Brooks (2011)

Quaternary Faults: mapping by
A. Ramelli, J. Bell

Geophysics: D. Ponce, J. Watt,
C. Bouligand (2011)

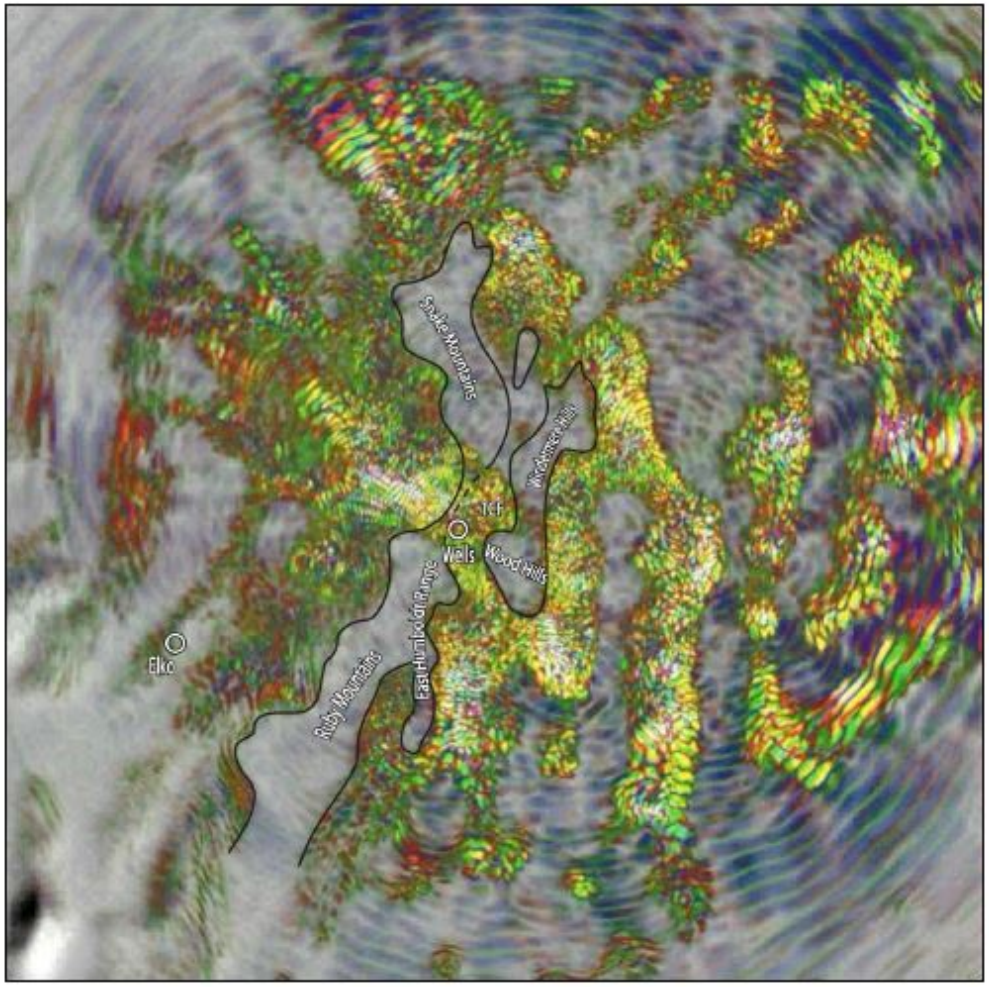
C. dePolo (2011)

Quaternary Tectonic Setting



R. Ramelli, C. dePolo (2011)

Ground Shaking Simulations



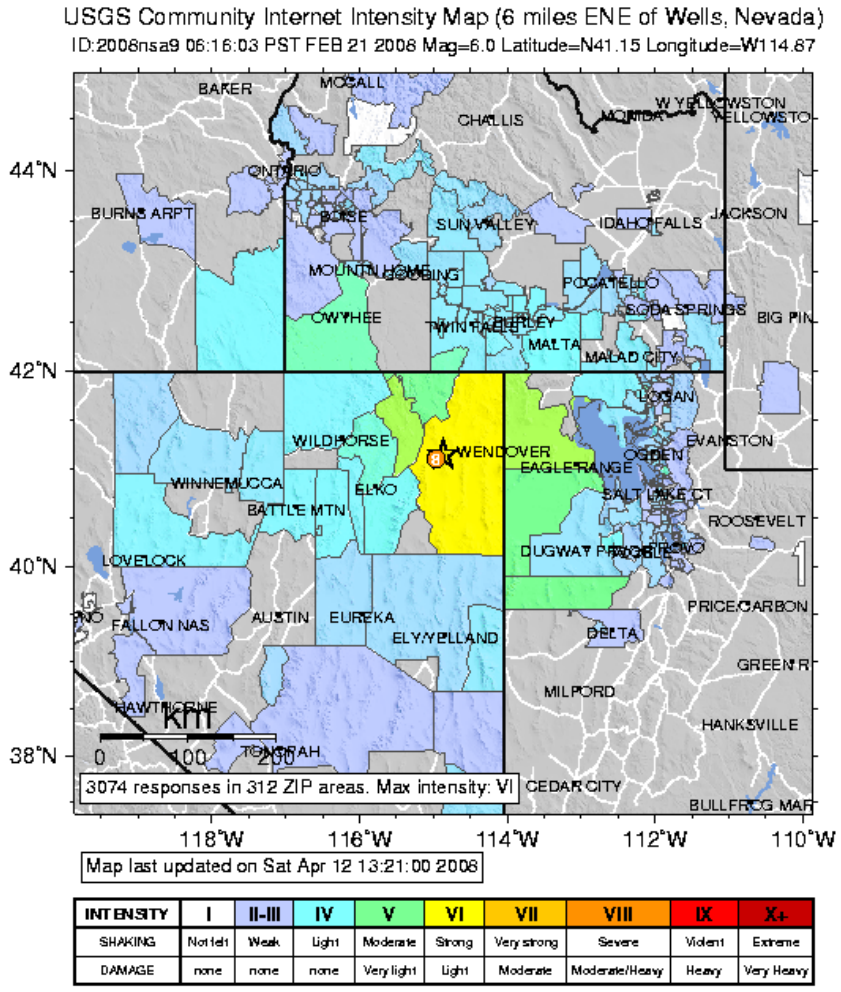
J. Louie (2011)

Earthquake Shaking Timeline (Stuart Market Security Camera)

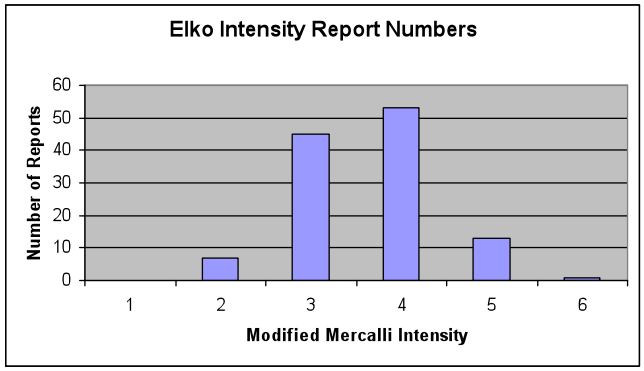
Seconds	**Shaking Effect**
0	start of earthquake
0 - 1.3	five vertical pulses
1.3 - 3	lateral wave pulses, some objects thrown
3 - 15	strongest ground motion, many objects thrown
15 - 23.4	moderate lateral shaking
23.4 - 45	calmer shaking – basin response

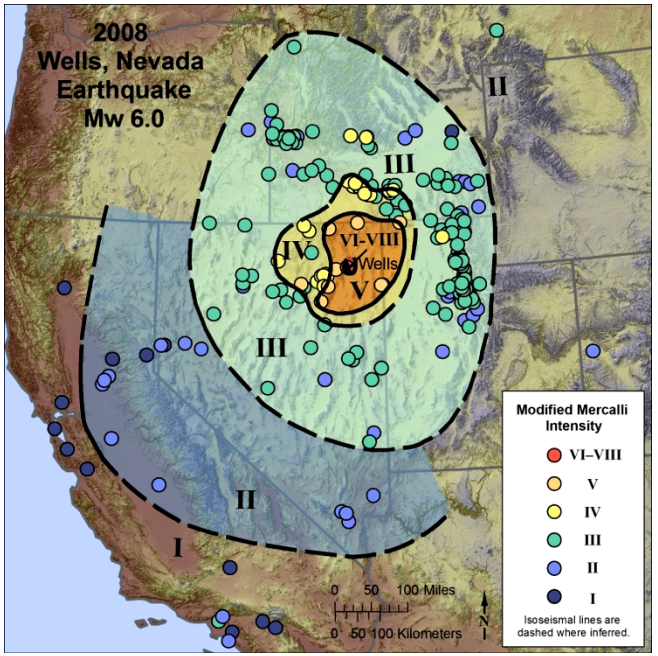
C. dePolo (2011)

Shaking Intensity (CIIM, MMI)

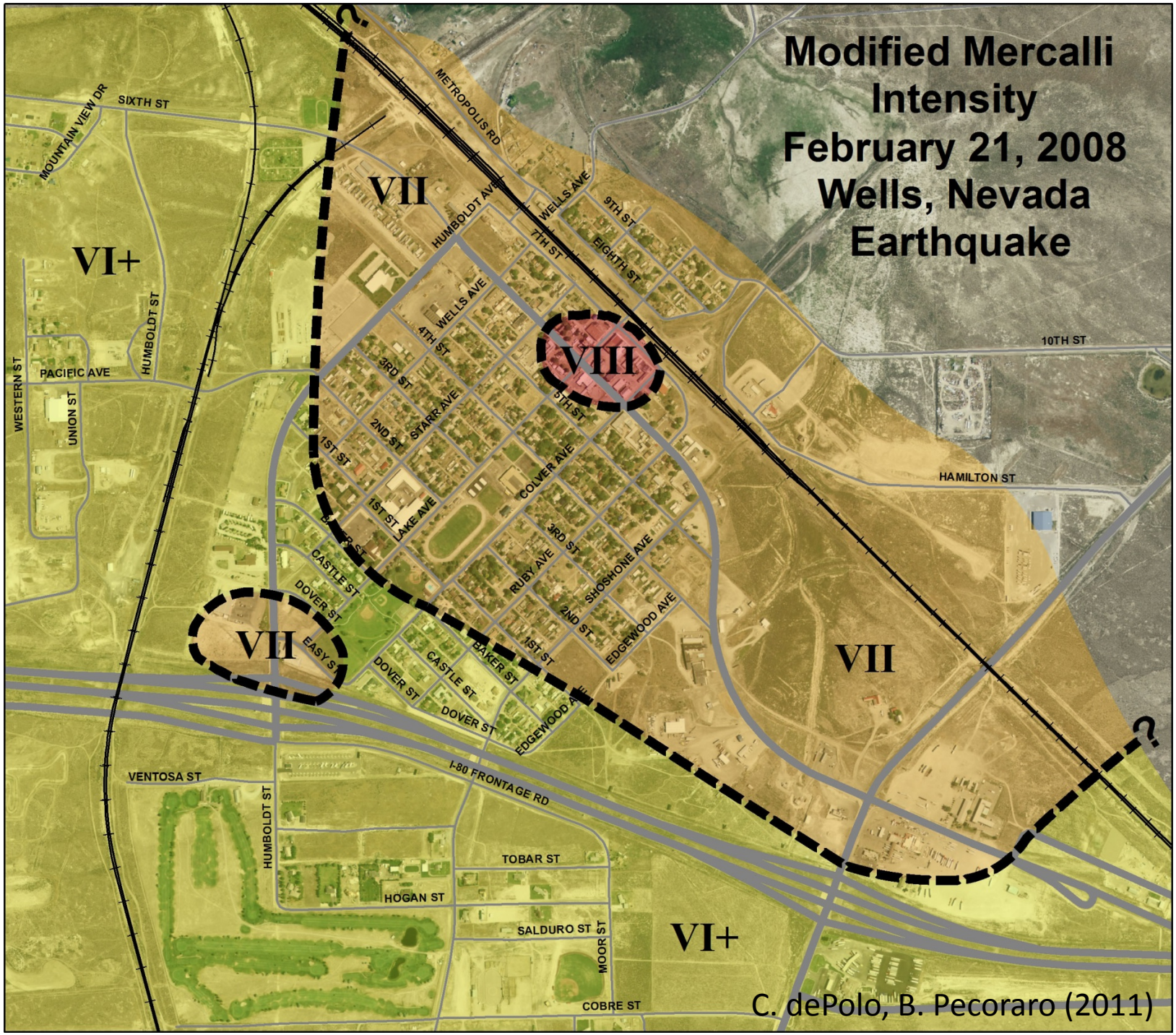


USGS website





C. dePolo, B. Pecoraro (2011)



C. dePolo, B. Pecoraro (2011)

Limited Surface Effects

- Several small rock falls, snow bank failures, boulders dislodged.
- No evidence of surface rupture.
- No evidence of liquefaction (ground frozen to 30 to 50 cm depths).

C. DuRoss, C. dePolo, R. Koehler, S. Bowman, G. McDonald, L. Shaw (2011)

Shaken Down Boulder – DuRoss +

The Way Things Moved

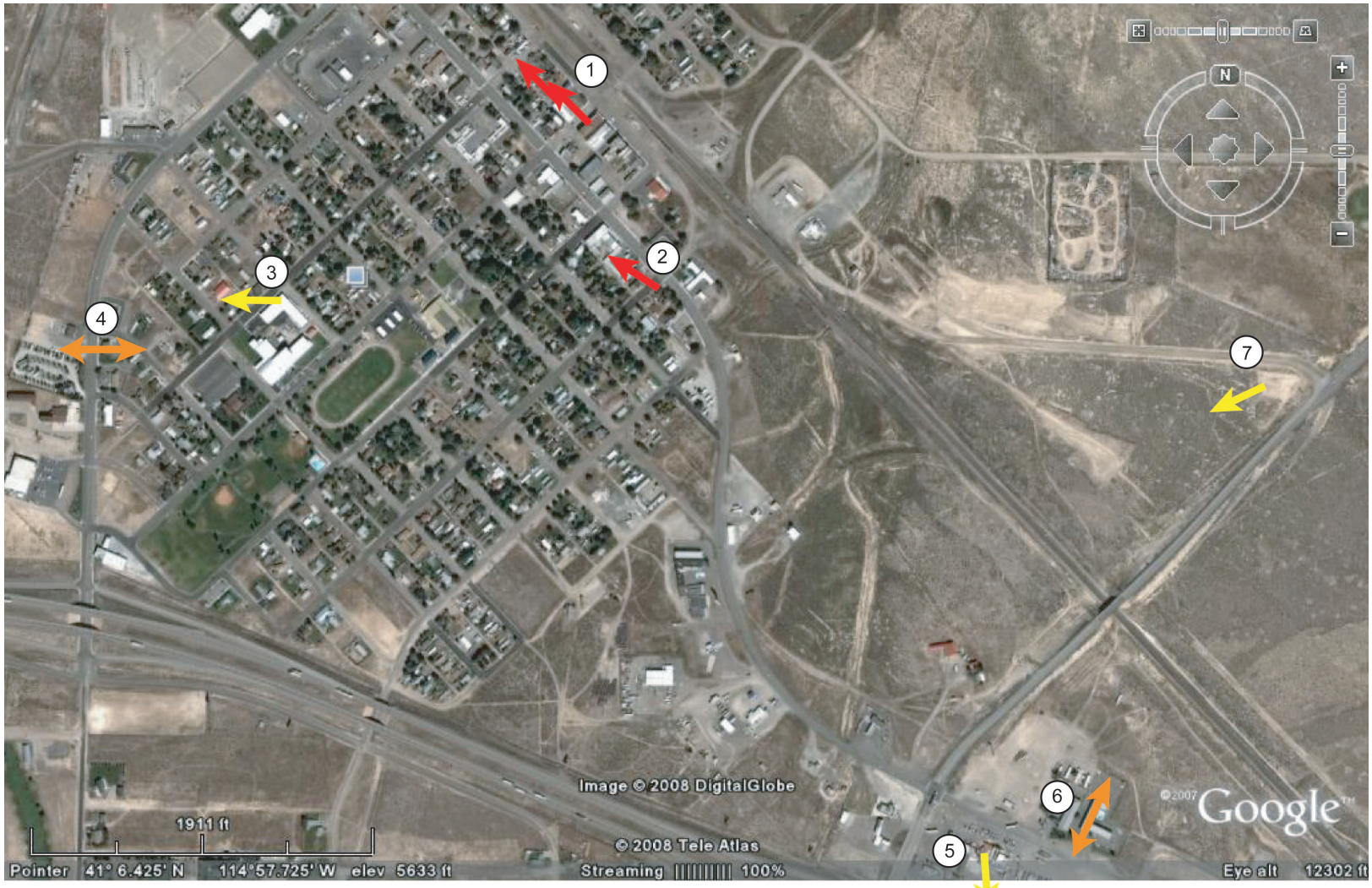
Heavy Press

Walkin’ Bandsaw

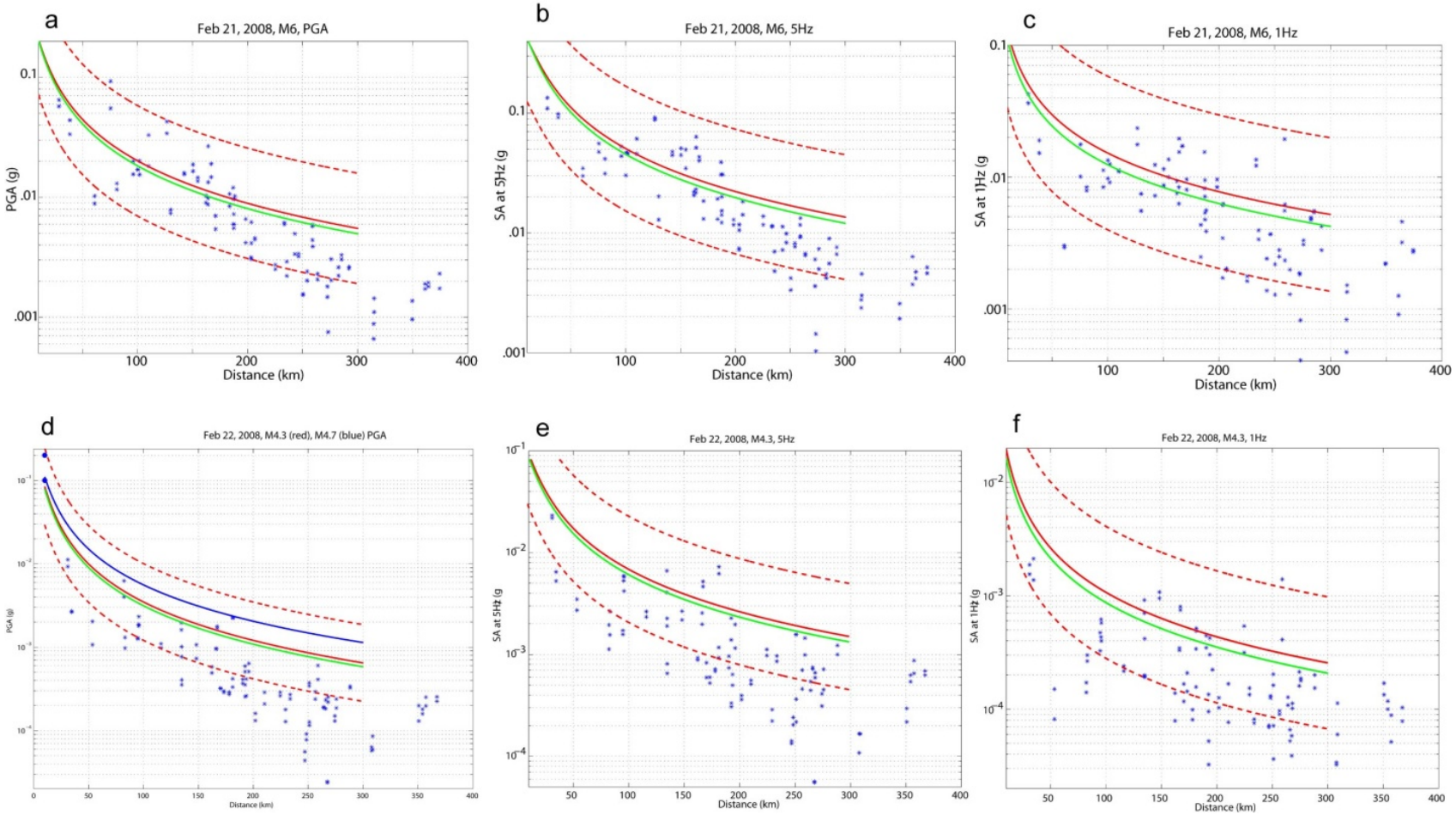
Large Fuel Tank Slid

Large Transformer slid

Sliding Directions

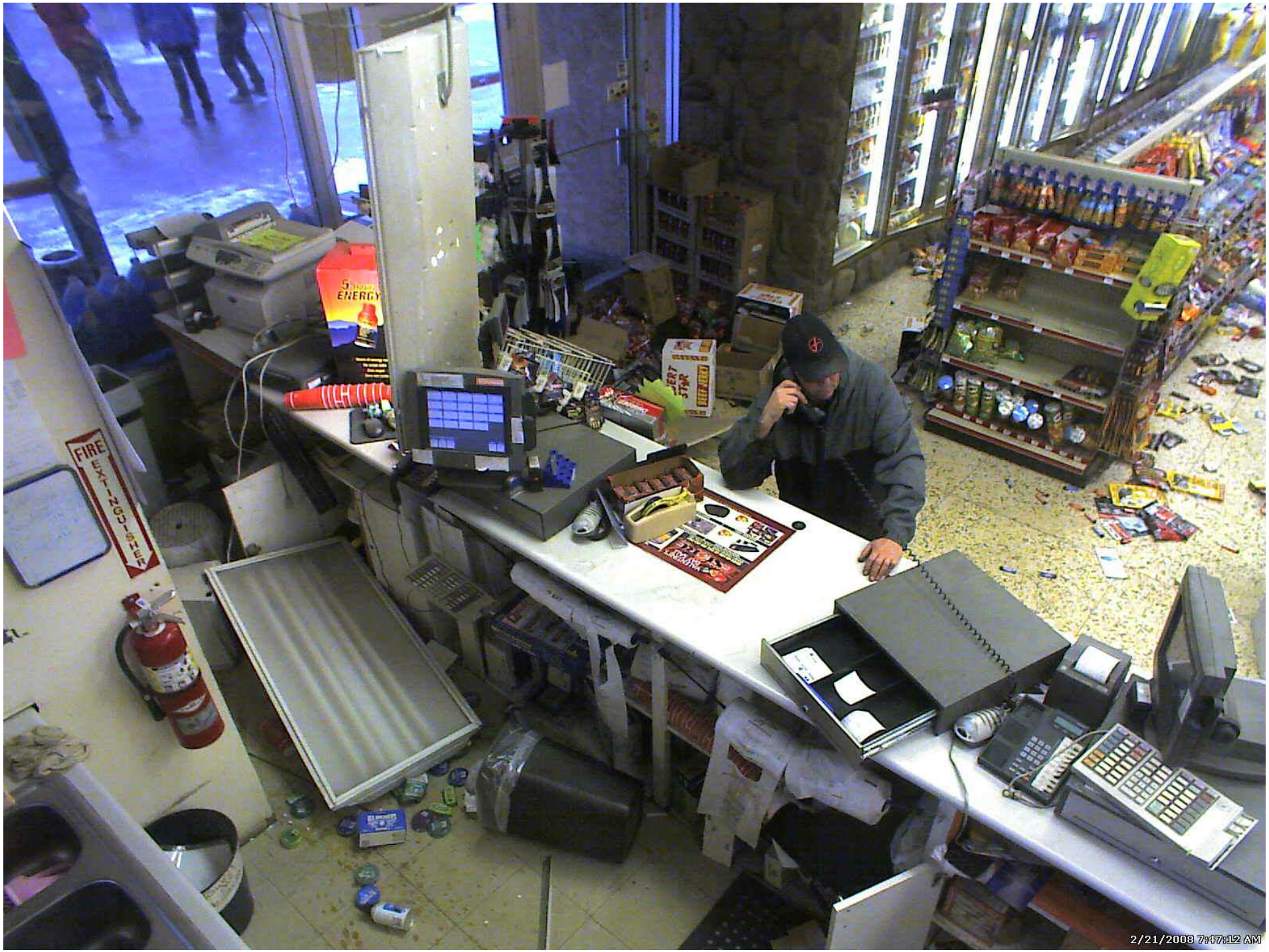


Ground Motion Studies

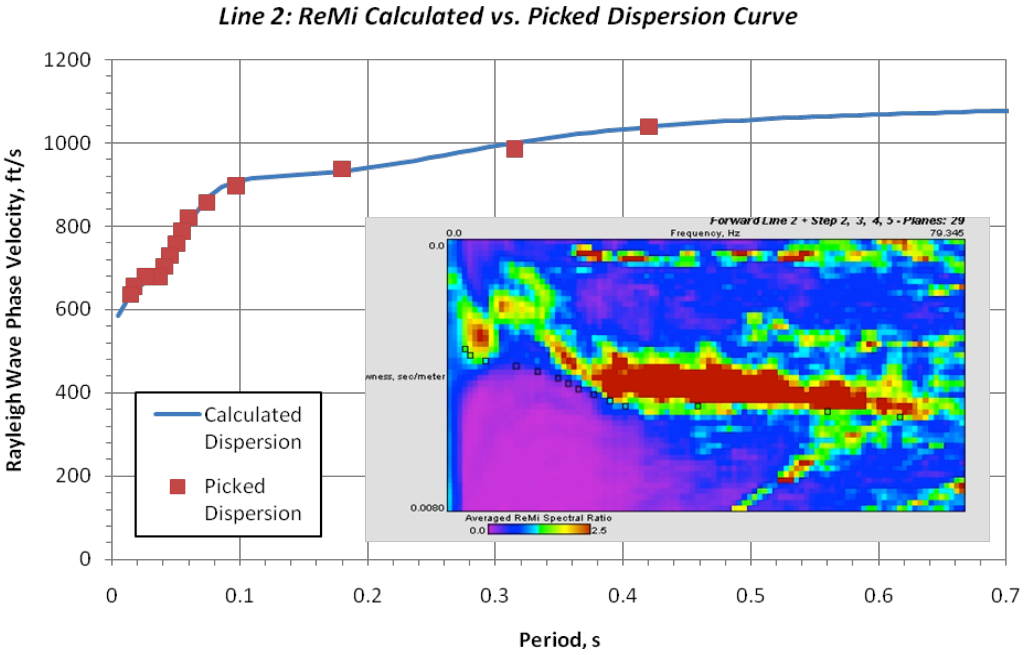


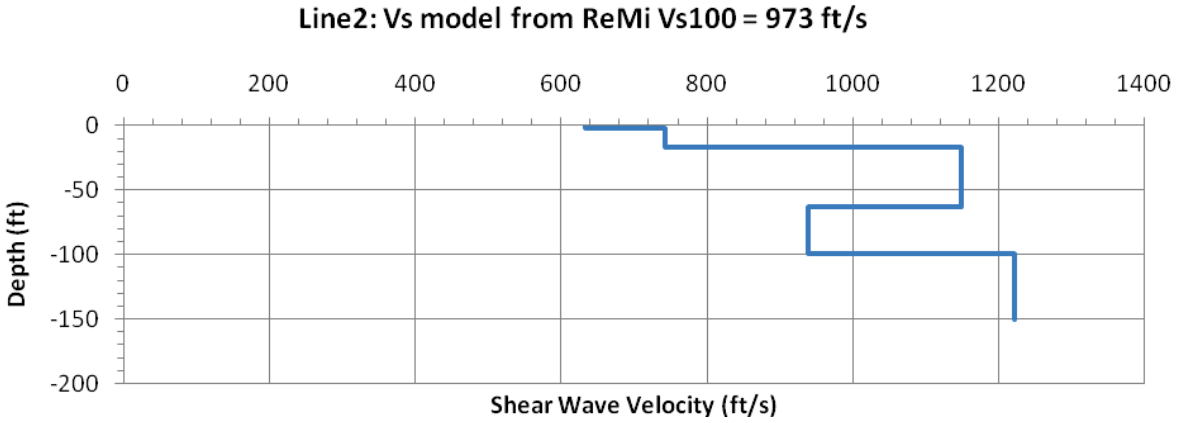
Campbell and Bozorgnia (2008) NGA curves: red – V_s30=270 m/s, green – V_s30=360 m/s

M. Petersen, K. Pankow, G. Biasi, M. Meremonte, S. Harmsen, C. Mueller, Y. Zeng (2011)


FIRE EXTINGUISHER
2/21/2008 7:47:12 AM

Shallow Shear Wave Velocities - ReMi





J. O'Donnell, A. Pancha,
C. dePolo (2011)

On February 21, 2008 a magnitude 6.0 earthquake struck Wells, Nevada...view press release

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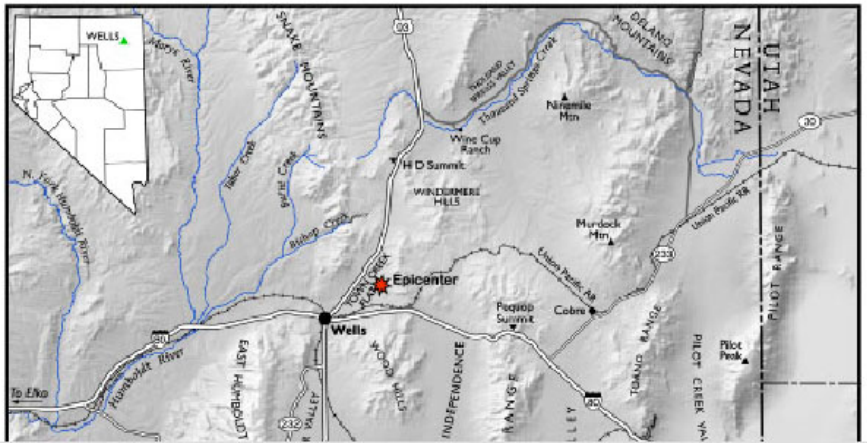
Tells us your story!

We want to hear your reports and see your photos and videos of the Wells earthquake.
Send your stories, photos or video to: webmaster@nbmg.unr.edu



NEVADA BUREAU OF MINES AND GEOLOGY

Wells, NV Earthquake Technical Clearinghouse

February 21, 2008

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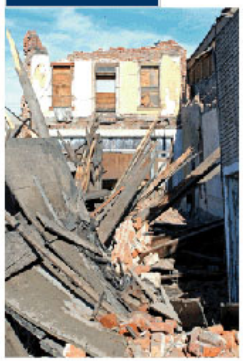
- Contacts



Please consider all reports preliminary. They are intended to help scientists, engineers, and emergency managers in their earthquake response and recovery efforts. They have not been edited or reviewed by peers, as will be done for fully published reports.

On February 21, 2008 at 6:16am, a magnitude 6.0 earthquake rocked the town of Wells, Nevada....**see reports and photos after the event.**

Wells is located in northeast NV.... **see history of Wells.**

Tells us your story!

We want to hear your reports and see your photos and videos of the Wells earthquake. Send your stories, photos or video to: **webmaster@nbmg.unr.edu**

Learn how to "**Beat the Quake**" -- **be prepared before the next earthquake strikes!**

Learn the **Steps to Earthquake Safety** and **download a flyer** (.pdf) to post in your

http://www.nbmg.unr.edu/Pubs/sp/sp36/index.html

Nevada Bureau of Mines and Geology Special Publication 36

The 21 February 2008 M_w 6.0 Wells, Nevada Earthquake

A compendium of earthquake-related investigations prepared by the University of Nevada, Reno

Edited by
Craig M. dePolo and Daphne D. LaPointe

2011

507 pages
35 papers
600 photos
geology map
eq. simulation

I. Summary

a. Summary of the 2008 Wells, Nevada Earthquake Documentation Volume
by Craig M. dePolo[1], Kenneth D. Smith[2], and Christopher D. Henry[1]
[1]Nevada Bureau of Mines and Geology and [2]Nevada Seismological Laboratory, University of Nevada, Reno

II. Introduction

a. An Introduction to the February 21, 2008, M_w 6.0 Wells Nevada Earthquake and the Earthquake Documentation Volume
by Craig M. dePolo, Nevada Bureau of Mines and Geology, University of Nevada, Reno

b. Seismicity and Seismic Hazard of Northeastern Nevada
by John G. Anderson, Nevada Seismological Laboratory, University of Nevada, Reno

c. Wells Earthquake Relief Fund Video (.wmv)
by Layla Walz, Wells Rural Electric Company

III. Geologic and Geophysical Setting

a. The Regional Structural Setting of the 2008 Wells Earthquake and Town Creek Flat Basin–Implications for the Wells Earthquake Fault and Adjacent Structures
by Christopher D. Henry[1] and Joseph P. Colgan[2]
[1]Nevada Bureau of Mines and Geology, University of Nevada, Reno and [2]U.S. Geological Survey, Menlo Park, CA

b. Bedrock Geology of the Ranges Bounding the Wells Earthquake of February 21, 2008
by Charles H. Thorman[1] and William E. Brooks[2]
[1]U.S. Geological Survey Emeritus, Denver, CO and [2]U.S. Geological Survey, Reston, VA

c. Quaternary Faults in the 2008 Wells Earthquake Area
by Alan R. Ramelli and Craig M. dePolo, Nevada Bureau of Mines and Geology, University of Nevada, Reno

d. Geophysical Setting of the February 21, 2008 M_w 6.0 Wells Earthquake, Nevada, Implications for Earthquake Hazards
by Ponce, D.A., Watt, J.T., and Bouligand, C., U.S. Geological Survey, Menlo Park, CA

e. Shallow Shear-Wave Velocities Based on Refraction Microtremor Measurements in Areas Damaged by the 2008 M_w 6.0 Wells, Nevada Earthquake
by Jim O'Donnell[1], Aasha Pancha[2], and Craig M. dePolo[3]
[1]Boulder City, Nevada, [2]Optim SDS, Reno, NV and [3]Nevada Bureau of Mines and Geology, University of Nevada, Reno

IV. Seismic and Infrasound Studies

a. Preliminary Analysis of the M_W 6.0 Wells, Nevada, Earthquake Sequence

by Kenneth Smith[1], Jim Pechmann[2], Mark Meremonte[3] and Kristine Pankow[2]
[1]Nevada Seismological Laboratory, University of Nevada Reno, [2]University of Utah Seismograph Stations, Salt Lake City, UT and [3]U.S. Geological Survey, Golden, CO

b. Preliminary Finite-Source Study of the February 21, 2008 Wells, Nevada Earthquake

by Douglas S. Dreger, Sean R. Ford, and Isabelle Ryder, Berkeley Seismological Laboratory

c. Empirical Green's Function Analysis of the Wells, Nevada, Earthquake Source

by Mendoza, C.[1] and Hartzell S.[2]
[1]Centro de Geociencias, Universidad Nacional Autonoma de Mexico and [2]U.S. Geological Survey, Denver, CO

d. Ground Motions from the 2008 Wells, Nevada Earthquake Sequence and Implications for Seismic Hazard

by Mark Petersen[1], Kris Pankow[2], Glenn Biasi[3], Mark Meremonte[1], Stephen Harmsen[1], Charles Mueller[1] and Yuehua Zeng[1]
[1]U. S. Geological Survey, Golden, CO, [2]University of Utah, Salt Lake City, UT and [3]University of Nevada, Reno

e. Infrasonic Observations from the February 21, 2008 Wells Earthquake

by Relu Burlacu[1], Stephen Arrowsmith[2], Chris Hayward[3], Brian Stump[3]
[1]University of Utah Seismograph Stations, [2]Las Alamos National Laboratory and [3]Department of Geological Sciences, Southern Methodist University

V. Geodetic and State-of-Stress Studies

a. Global Positioning System Constraints on Crustal Deformation Before and During the 21 February 2008 Wells, Nevada M 6.0 Earthquake

by William C. Hammond[1], Geoffrey Blewitt[1], Corné Kreemer[1], Jessica R. Murray-Moraleda[2] and Jerry L. Svarc[2]
[1]Nevada Bureau of Mines and Geology, University of Nevada, Reno and [2]U.S. Geological Survey, Menlo Park, California

b. Coulomb Stress Analysis of the 21 February 2008 M_W = 6.0 Wells, Nevada, Earthquake

by Volkan Sevilgen, U. S. Geological Survey, Menlo Park, CA

VI. Earthquake Damage and Effects

a. Modified Mercalli Intensity Maps for the February 21, 2008 Wells, Nevada Earthquake
by Craig M. dePolo and Bret Pecoraro, Nevada Bureau of Mines and Geology, University of Nevada, Reno

b. Building Damage from the 2008 Wells, Nevada Earthquake
by Craig M. dePolo, Nevada Bureau of Mines and Geology, University of Nevada, Reno

c. Damage to Residential Houses from the 2008 Wells, Nevada Earthquake
by Craig M. dePolo, Nevada Bureau of Mines and Geology, University of Nevada, Reno

d. Wells High School Analysis and Reconstruction Following the February 21, 2008 Earthquake
by Thomas E. Trabert, M.S., P.E., Trabert Engineering, Reno, NV

e. 2008 Wells, Nevada Earthquake: Effects on Utility Systems
by Craig M. dePolo[1] and Mike Ericksen[2]
[1]Nevada Bureau of Mines and Geology, University of Nevada, Reno and [2]Wells Propane, Inc.

f. Wells, Nevada M6.0 Earthquake Impact on the Nevada Department of Transportation
by Michael E. Murphy, Nevada Department of Transportation, District III, Elko, NV

g. Effects on Geothermal Features Following the February 21, 2008 Wells, Nevada Earthquake
by Chris Sladek, Department of Geological Sciences, University of Nevada, Reno, Nevada

VII. Response to the Earthquake, Community Impacts, and Disaster Recovery

a. The Emergency Response to the 2008 Wells, Nevada Earthquake Disaster
by Craig M. dePolo[1] and Dale Lotspeich[2]
[1]Nevada Bureau of Mines and Geology, University of Nevada, Reno and [2]Elko County Sheriff's Department

b. Loss-Estimation Modeling Based on the 2008 Wells, Nevada Earthquake
by Jonathan G. Price, Ronald H. Hess, Gary L. Johnson, Craig M. dePolo, and Jordan T. Hastings
Nevada Bureau of Mines and Geology, University of Nevada, Reno

c. Immediate Scientific Response to the 2008 Wells, Nevada, Earthquake
by DuRoss, C.B.[1], dePolo, C.M.[2], Koehler, R.D.[4], Bowman, S.D.[1], McDonald, G.N.[1] and Shaw, L.M.[3]
[1]Utah Geological Survey, [2]Nevada Bureau of Mines and Geology, University of Nevada, Reno, [3]Northern Arizona University; formerly Utah Geological Survey and [4]University of Nevada, Reno

d. The Impact of the 2008 Wells, Nevada Earthquake on the City of Wells: Post-Earthquake Lessons for Rural Community Governments
by Craig M. dePolo[1] and Jolene Supp[2]
[1]Nevada Bureau of Mines and Geology, University of Nevada, Reno and [2]City of Wells

e. The Recovery of Wells, Nevada from the 2008 Earthquake Disaster
by Craig M dePolo, Nevada Bureau of Mines and Geology, University of Nevada, Reno

VIII. Lessons Learned

a. Lessons Learned from the February 21, 2008 Wells, Nevada Earthquake
by Nevada Earthquake Safety Council with contributions and support from Nevada Bureau of Mines and Geology, Nevada Seismological Laboratory, Nevada Division of Emergency Management, Federal Emergency Management Agency, U.S. Geological Survey and City of Wells

Appendices

Appendix A. Plate 1. Geologic Map of the Wells Area, Elko County, Nevada [dowload GIS data]
Compiled by Christopher D. Henry[1] and Charles H. Thorman[2]
[1]Nevada Bureau of Mines and Geology and [2]U.S. Geological Survey Emeritus, Denver, CO

Appendix B. Interferometric Synthetic Aperture Radar Map of the 2008 Wells Earthquake
by John W. Bell, Nevada Bureau of Mines and Geology, University of Nevada, Reno

Appendix C. Photograph Gallery

Appendix D. Objects that were Thrown, Toppled or Slid by the 2008 Wells, Earthquake
by Craig M. dePolo, Nevada Bureau of Mines and Geology, University of Nevada, Reno

Appendix E. Preliminary Earthquake Simulations for the 21 February 2008 Wells Earthquake
by John Louie, Nevada Seismological Laboratory, University of Nevada, Reno

Apple version (PowerPoint includes .mov files)

Windows version (PowerPoint includes .avi files)

Appendix F. Wells Nevada earthquake–A 6.0 magnitude earthquake strikes the northeastern edge of the Basin and Range
by Corné Kreemer, Nevada Bureau of Mines and Geology, University of Nevada, Reno

Advice for working an earthquake disaster

- **It is all about them – not you**
- **People need to talk – listen – you will be rewarded**
- **Stay with the community a couple months – attend their events**
- **Be available when you are needed**
- **You are an expert – be reassuring – give strokes**
- **People will become amateur seismologists to gain control – facilitate this effort**
- **Be a friend**
- **Document, document, document; write your report every night**

EMERGENCY RESPONSE – 2008 M6 WELLS, NEVADA EARTHQUAKE

Rich Harvey
Deputy State Forester (retired), Nevada Division of Forestry

The following is a PDF version of the author's PowerPoint presentation.

EMERGENCY RESPONSE
M6 EARTHQUAKE
WELLS, NEVADA, FEBRUARY 21, 2008

Rich Harvey
Nevada Division of Forestry Deputy State Forester – Retired
Incident Commander

The Initial Response

ROOMS
CHALET
FIRE

SYSCO
15242
Beraluft

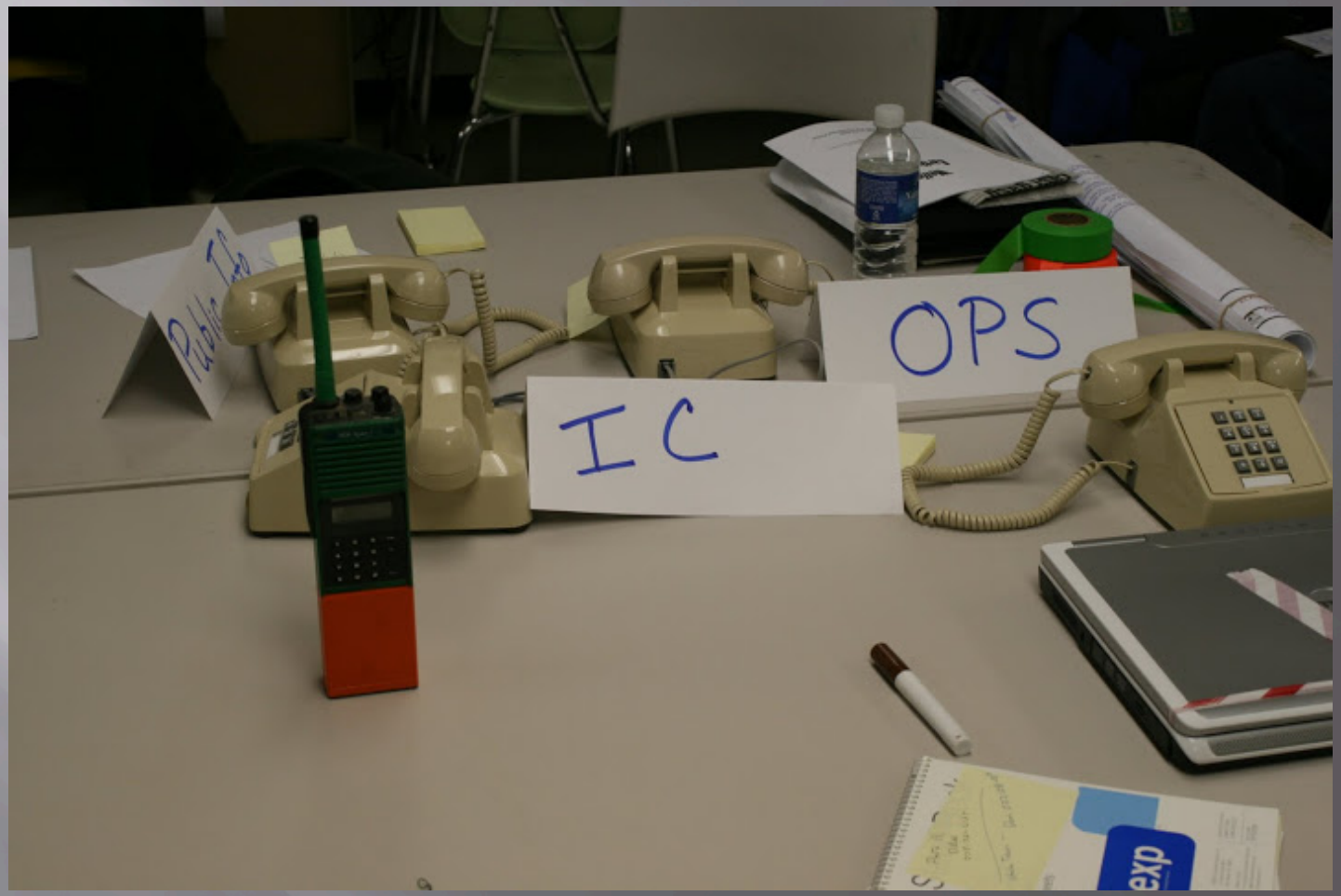
S. QUILICI & SONS

S. QUILICI & SONS

Incident Command Post

Unified Command

Incident Action Plan


OPS
IC

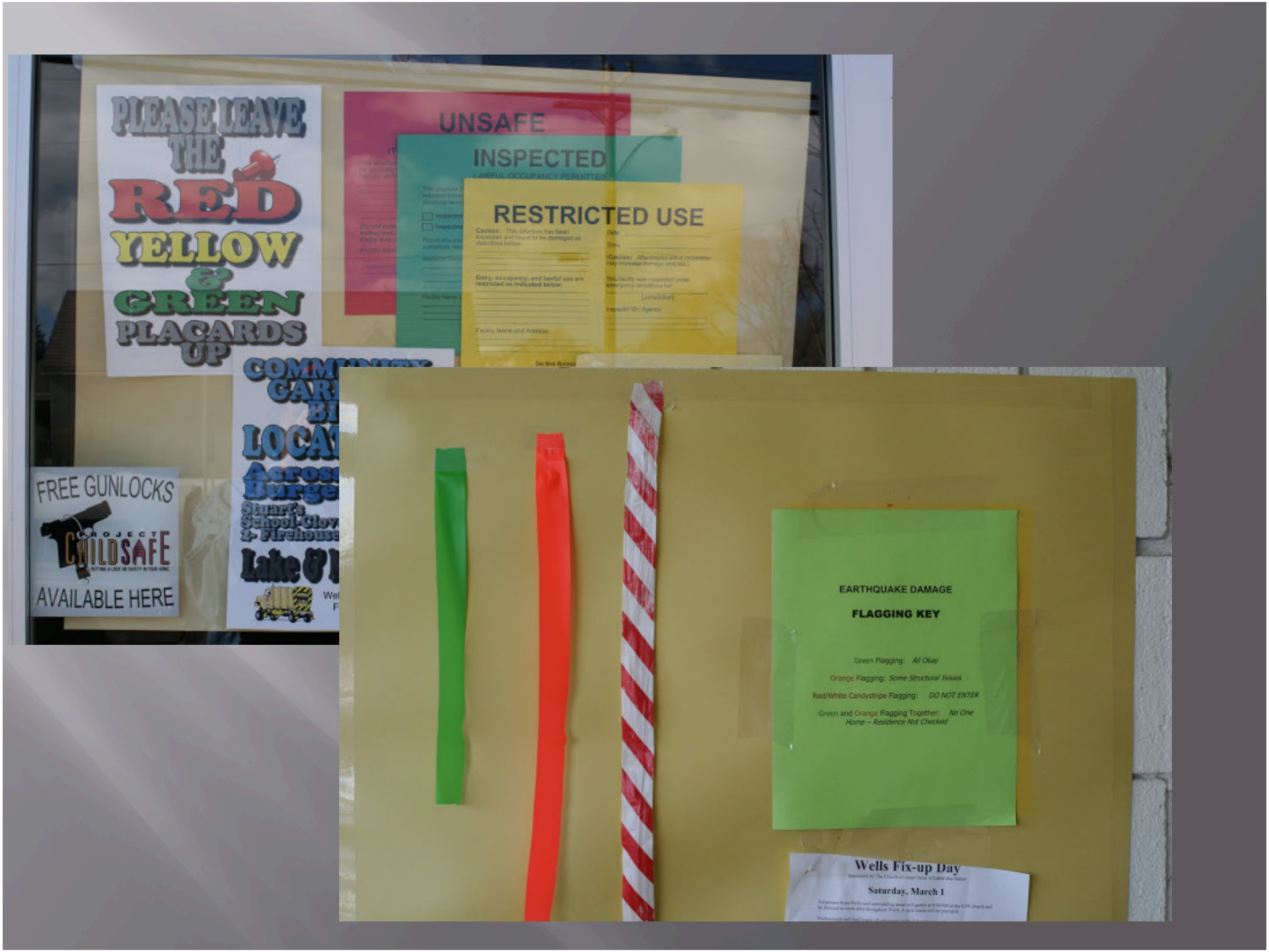
600 Residential and Commercial Safety Inspections the first day

Rather Quickly

A bit more Helpful

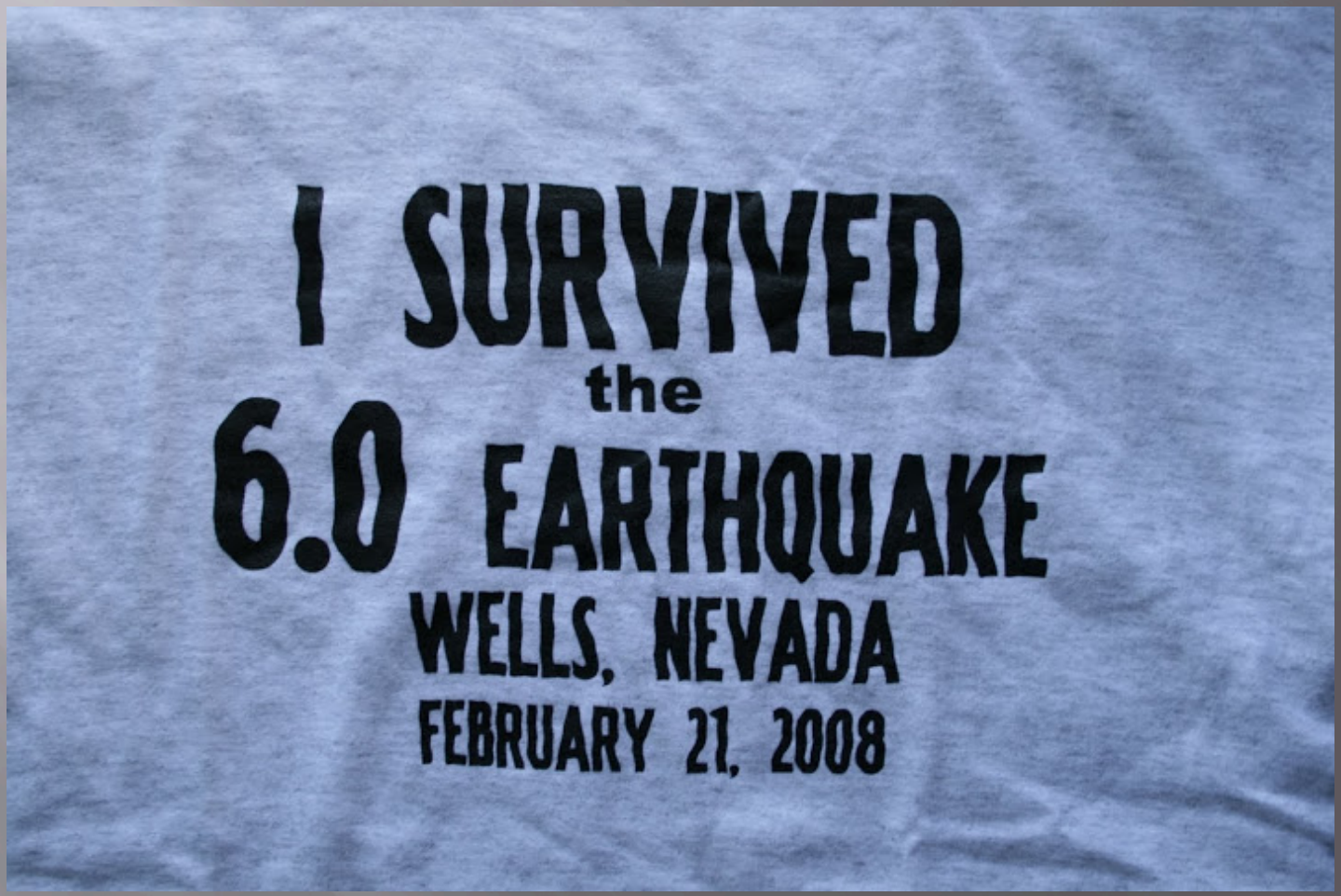
EXIT

Of Course it would Snow that night


PLEASE LEAVE THE RED YELLOW & GREEN PLACARDS UP
UNSAFE
INSPECTED
LAWFUL OCCUPANCY PERMITTED
RESTRICTED USE
FREE GUNLOCKS
PROJECT CHILDSAFE
AVAILABLE HERE
EARTHQUAKE DAMAGE
FLAGGING KEY
Green Flagging: All Okay
Orange Flagging: Some Structural Issues
Red/White Candystripe Flagging: DO NOT ENTER
Green and Orange Flagging Together: No One Home – Residence Not Checked
Wells Fix-up Day
Saturday, March 1

SORO
2:42
SCHOOL BUS

CAT


I SURVIVED
the
6.0 EARTHQUAKE
WELLS, NEVADA
FEBRUARY 21, 2008

ENGINEERING CONSIDERATIONS

Barry Welliver
13623 S. Bridle Trail Road, Draper, Utah 84020
bhwelliver@me.com

Immediately following the February 21, 2008 Wells, Nevada earthquake, members of the Structural Engineers Association of Utah (SEAU) offered their assistance to the local building department for the rapid evaluation of buildings in the affected area. The recently formed Structural Engineers Emergency Response committee (SEER) provided volunteers trained in the Applied Technology Council's ATC-20 Rapid Visual Screening of Buildings for Potential Seismic Hazards to help "tag" buildings for safety purposes. The program took place over a two-week period following the earthquake and provided supplemental help to the community as they recovered from the event.

ABOUT THE SPEAKER

Barry Welliver, a licensed structural engineer with offices in California, Utah, and Oregon, specializes in the rehabilitation of existing buildings. He has served the Structural Engineers Association of Utah (SEAU) as chair of several committees and as a past president. He served the Utah Seismic Safety Commission as a delegate from SEAU and as chairman from 2002-2006. Barry helped author the Federal Emergency Management document Engineering Guideline for Incremental Seismic Rehabilitation (FEMA P-420, May 2009). He has been an advocate for legislation to perform rapid visual screening of all public schools in Utah.

The following is a PDF version of the author's PowerPoint presentation.

2008 M6 WELLS, NV EARTHQUAKE

FEBRUARY, 2008

Engineering Considerations

Structural Engineers Association of Utah

Barry H. Welliver

Structural Engineer

Content

1. Structural Engineers Association Overview
2. Utah Structural Engineers Emergency Response
3. Wells Post-Disaster Inspections
4. Post-Response Issues
5. Lessons and Opportunities

1. SEAU Organization

www.seau.org

Structural Engineers Association of Utah

Established in 1980, membership of approximately 300 engineers

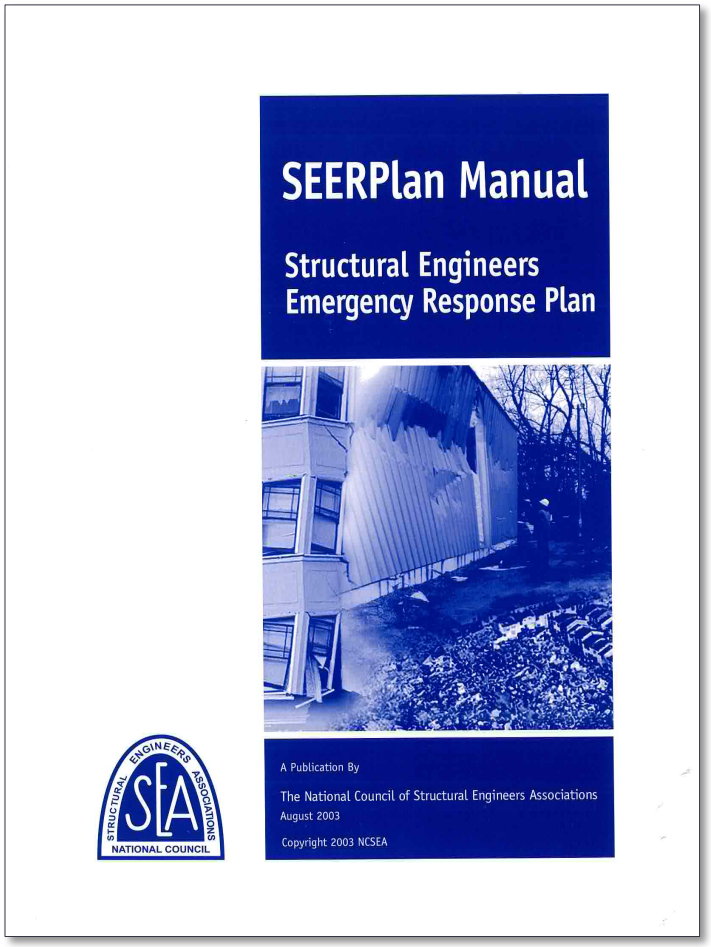
Promote public awareness of structural engineering

Committee structure to support technical and practical aspects of the profession.

Structural Engineers Emergency Response committee (SEER) formed in 2002.

Created separate structural licensure through SB 200 in 2008 Legislative session

2. Structural Engineers Emergency Response Committee



Utah's SEER

Modeled after NCSEA program

Established after Sept. 11, 2001 when City of New York asked SEAoNY to organize teams to provide assistance with disaster

Other programs:

- California Post-Disaster Safety Assessment Program (SAP)
- Utah Safety Assessment Program
- Applied Technology Council ATC-20 "Procedures for Post-Earthquake Safety Evaluation of Buildings"

SEER Program

How Does it Work?

Local Jurisdiction requests assistance

SEAU SEER committee helps organize "teams" including building officials, structural engineers and others prepared to evaluate damaged buildings

Teams visit affected buildings and "tag" structures based on safety requirements.

Reports filed with authority having jurisdiction for follow-up.

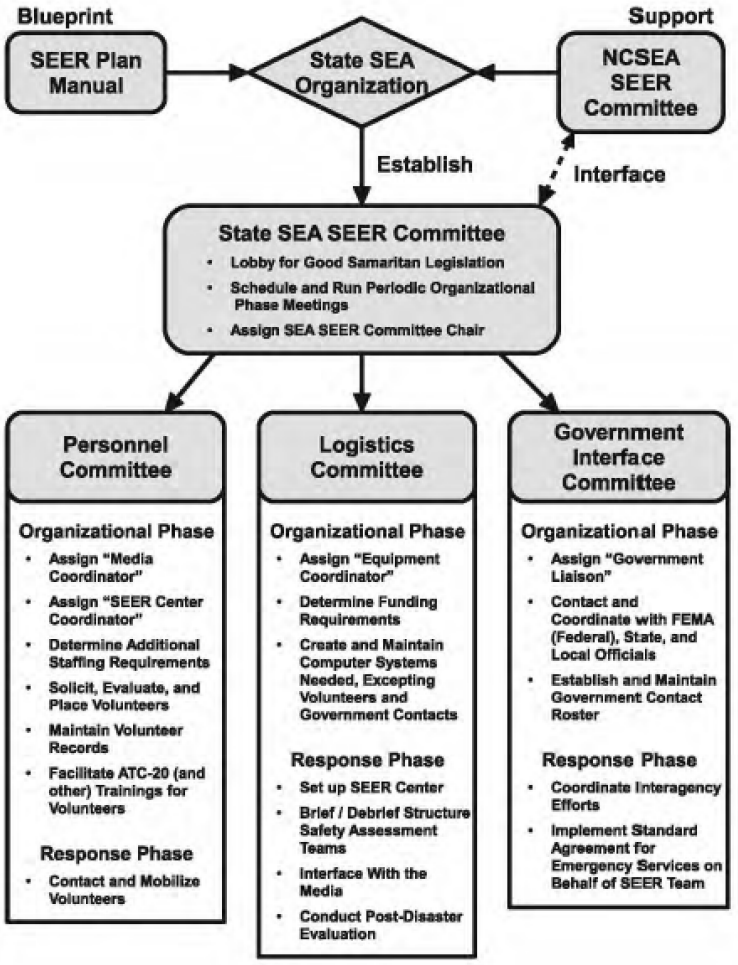


Figure 1.1 Implementing the SEERProgram

SEER Manual, 2nd edition | 9

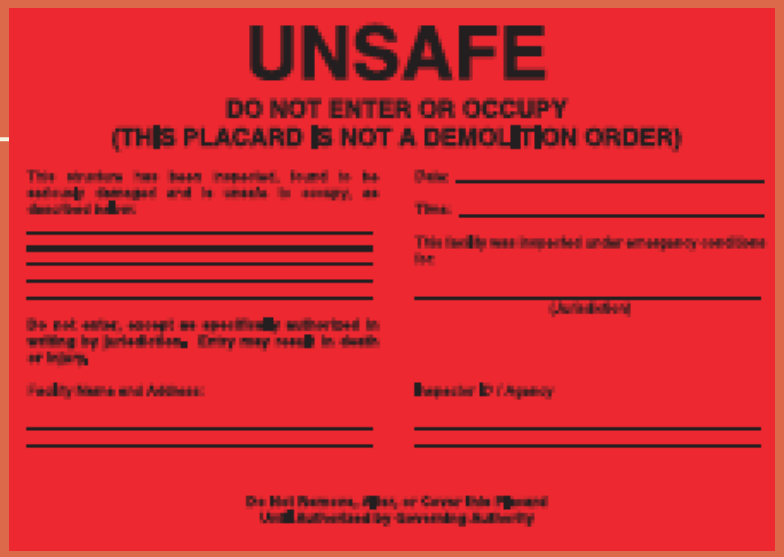
SEER PROGRAM

ATC Placards

Green = Inspected

Yellow = Restricted Use

Red = Unsafe



Utah SEER Response

Timeline:

- Feb. 21 — Event occurs – Glen Palmer responds
- Feb. 22 — UT SEER offers assistance to Wells
- Feb. 23 — Wells responds – yes, provides contact
- Feb. 23 – 29+ — UT SEER members respond (7-10 SEER + Others?)

Wells Building Department:

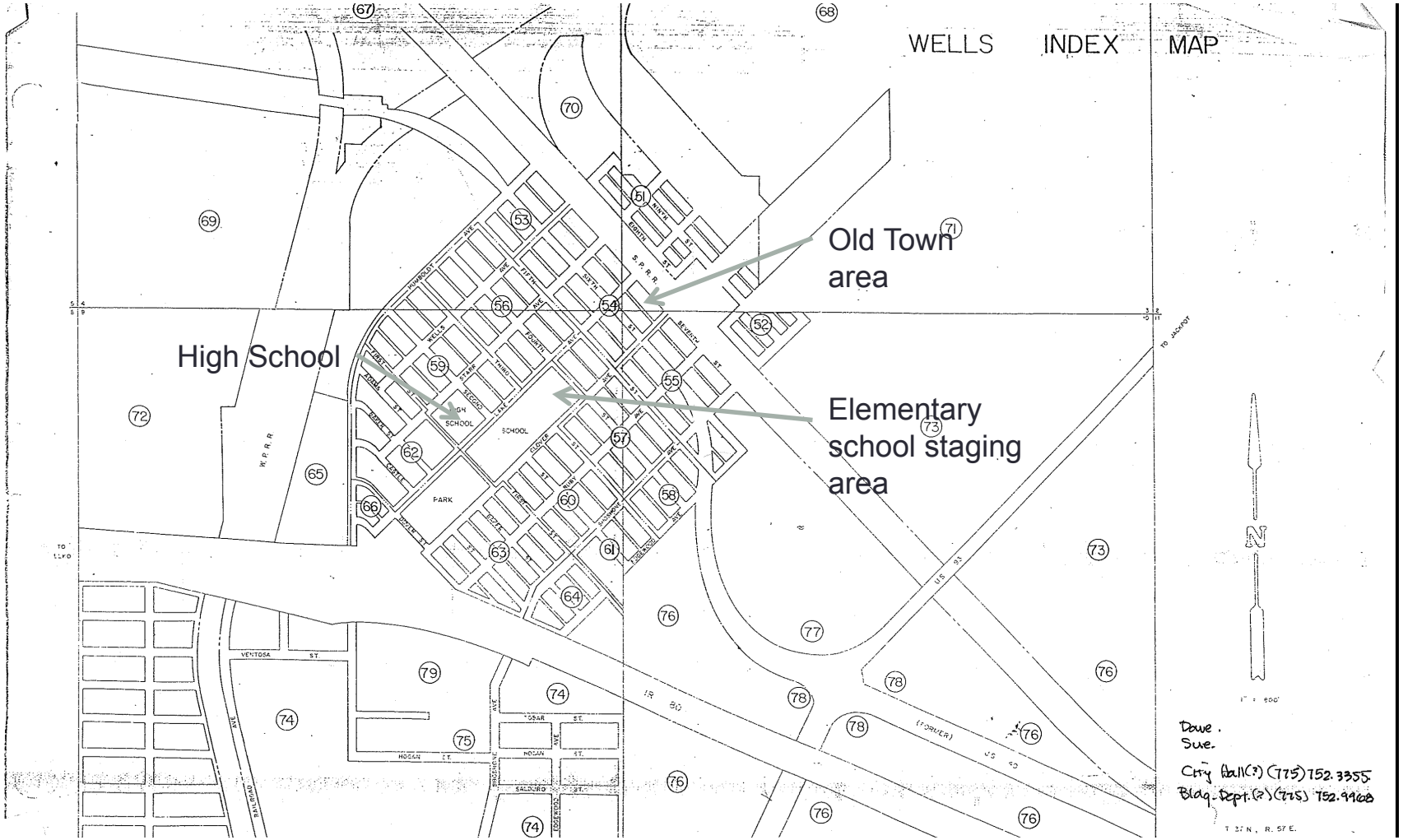
- Part-time Building Inspector from Elko
- City Manager (Jolene Supp) makes overview decisions

3. Post-Disaster Inspections

Inspection Process:

- Inspector registers with building department
- Receives “pairing” with another volunteer
- Field Experiences:
  - Visit sites, assess and tag buildings
  - Interactions with owners
  - Chimneys and flues
  - Venting issues
  - High school chimney demolition
- Filings and Completion

Area Map

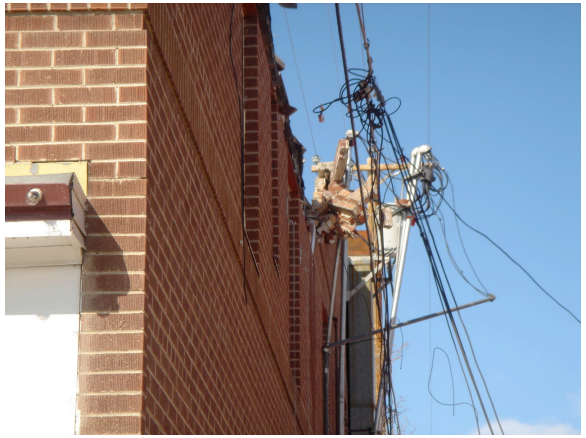

WELLS INDEX MAP
Old Town area
High School
Elementary school staging area
Dave.
Sue.
City Hall(?) (775) 752.3355
Bldg. Dept.(?) (775) 752.9908

Old Town – Lake Avenue

Old Town – Sixth Street

El Rancho Hotel

El Rancho Hotel



Chalet Bar & Casino

Chalet Bar & Casino

Bulls Head

Seventh Street

Seventh Street

Seventh Street – Two Story Bldg.

Nevada Hotel

Nevada Hotel - Before

Sixth Street

Wells High School

Wells High

Wells High Chimney

Wells High Chimney

Wells High School

Houses

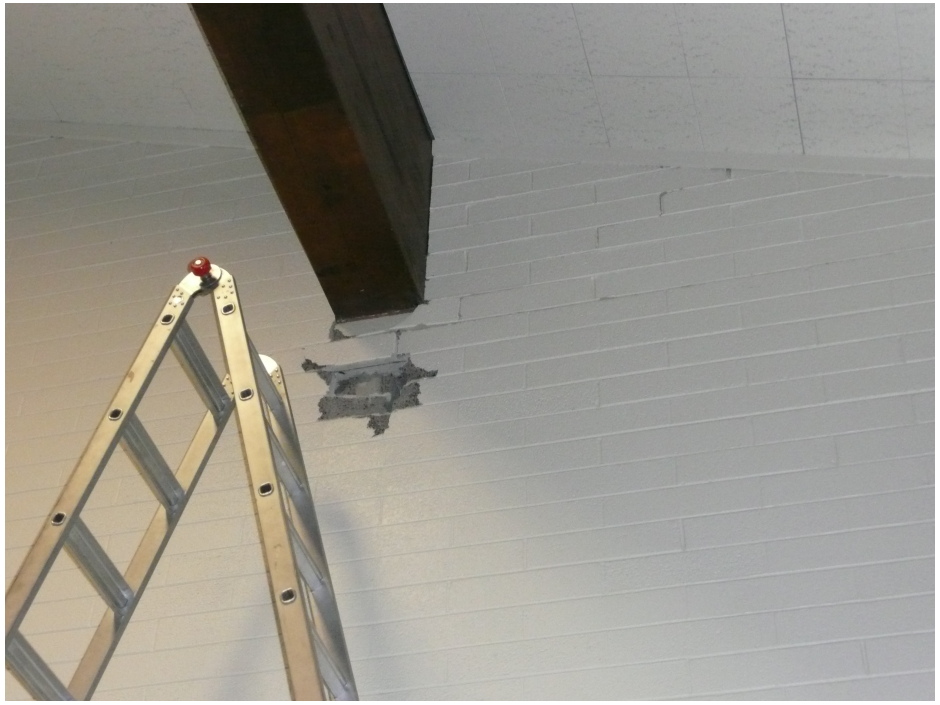
Stone House

Houses

Houses – Non Structural Damage

Motel

Church



4. Post - Response Issues

- Owners seeking engineering solutions at time of inspection
- City Officials assuming more detailed inspections to be performed by volunteers
- Guidance for rebuilding

5. Lessons and Opportunities

- Volunteer SEER organizations:
  - Can/should assist in educating city officials unfamiliar with post-disaster inspection process
- Goldilocks Response:
  - Just the right amount of resources (C. dePolo)
  - How many inspectors?
- UT Structural Assessment Program
  - Building Officials + engineers
  - Certification programs (Tier 1 and Tier 2)
- Building Occupancy & Resumption Programs (BORP)
  - Solutions for quicker recovery

THANKS

Barry H. Welliver
bhwelliver@mac.com

THE RECOVERY OF WELLS, NEVADA FROM THE FEBRUARY 21, 2008, MW 6.0 EARTHQUAKE

Craig M. dePolo
Nevada Bureau of Mines and Geology, MS-178, University of Nevada, Reno
1664 N. Virginia Street, Reno, Nevada, 89557
cdepolo@unr.edu

The community of Wells, Nevada recovered relatively quickly from the damaging 2008 magnitude 6 earthquake, even though some aspects took years to resolve. The citizens used their pioneering spirit to help one another during and immediately following the emergency response, and strategized getting back to normalcy as rapidly as possible. Some of the earliest recovery occurred when available emergency responders removed precarious damaged chimneys and plugged the holes in roofs to mitigate the loss of heat on the cold February days. In addition, they inspected chimneys, helped reset fire inserts, and made sure elderly residents had some extra help cleaning up acute or threatening damage. Small acts went a long way in restoring people's sense of well-being, helping them regain control over their lives, and in keeping their attitude positive and productive. Donations to the effected population came in the form of volunteers (both professional and labor), supplies for rebuilding and repair, and money. For assistance with smaller cleanups and repairs, a piece of white cloth was tied to car antennas or mailboxes and volunteers would come by on Saturdays to help. For larger losses, there were a few options for reconstruction. This was not a federally declared disaster, but it was a city-, county-, and state-declared disaster. The main financial relief funds available included earthquake insurance, a state homeowner disaster fund, donations from individuals and businesses across the state, proceeds from a recovery rally, and loans from the Small Business Administration (SBA). Applications for these funds were submitted to the state, SBA, or to a locally organized task force of multi-denominational religious leaders, which distributed the donated funds.

The total cost of the 2008 Wells earthquake was > $10.5 million (tabulated in 2010). The total relief funding available was $6.7 million, leaving > $3.8 million of loss to be borne by the community and individuals. Remarkably, earthquake insurance accounted for 72% of the relief funds, or 46% of the total known cost of the earthquake. The next largest relief fund was from an earmark on a federal omnibus bill by the Nevada delegation of $940,000, or about 9% of the total cost. SBA loans were about 4% of the total cost. Three homes were demolished and replaced and a number of commercial buildings needed to be torn down.

The City of Wells engaged in a series of events to facilitate recovery efforts. Dumpsters were placed around town so people could dispose of damaged goods and begin cleanup efforts, and city crews quickly repaired broken water lines. Wells hosted a recovery rally 43 days after the earthquake as a milestone, to show that the disaster was behind them and they were well on their way to rebuilding. Other community activities went on as scheduled to reinforce a return to normalcy. On the anniversary of the earthquake, Wells hosted a safety fair in the rebuilt high school gym to address anxieties people were having and get out information on how to get further prepared for a number of natural hazards.

Wells seized the opportunity side of recovery and has significantly reduced its earthquake risk for future events by rebuilding and rehabilitating several public buildings. The disaster brought the community together, and brought to the forefront some outstanding character of individuals. The stress on the community was nevertheless unmistakable as well with an increase of folks passing away and families leaving town.

The following is a PDF version of the author's PowerPoint presentation.

The Recovery of Wells, Nevada from the 2008 Magnitude 6 Earthquake

Craig M. dePolo

Nevada Bureau of Mines and Geology

Wells Recovery Video

Three Potential Outcomes of Community Recovery

Community recovery from an earthquake disaster determines whether it returns to its **prior standard of living**,

or there is a **permanent loss** to a community,

or it gains some **enhanced livelihood**.

Recovery of a community from a disaster such as an earthquake is a critical phase that has to be **engaged in as rapidly as possible**.

Yet it is one of the **least planned for activities** by a community. Most communities do not have recovery plans.

It is more or less assumed that it will just happen. But **an earthquake disaster is a lousy time for critically thinking and planning**.

2008 Wells, Nevada Earthquake

- M6 within a few kilometers of a community.
- Building damage, minor infrastructure damage, lots of nonstructural and content damage.
- Individual losses: few hundred to several thousand dollars; one family lost >$1M.
- >$10.5M cost and loss to community.
- Town closed for two to three days. Cordoned off damage areas for 6 years.

Human to Human Support

- **Pioneering Spirit** – engage in problems quickly and put energy into solving them until they are fixed.
- **Check on you neighbor**.
- Help organized by **community and spiritual leaders**.
- Community responded as **a collective**.

Fix-Up Day

Recovery began with the stabilization or removal of damaged elements in otherwise undamaged settings

- Recovery workers that were not being used helped folks out.
- Garbage bins were put out so folks could get rid of broken stuff – get it out of site and dealt with.
- Repair of broken water pipes; temporary fix then a permanent fix later.

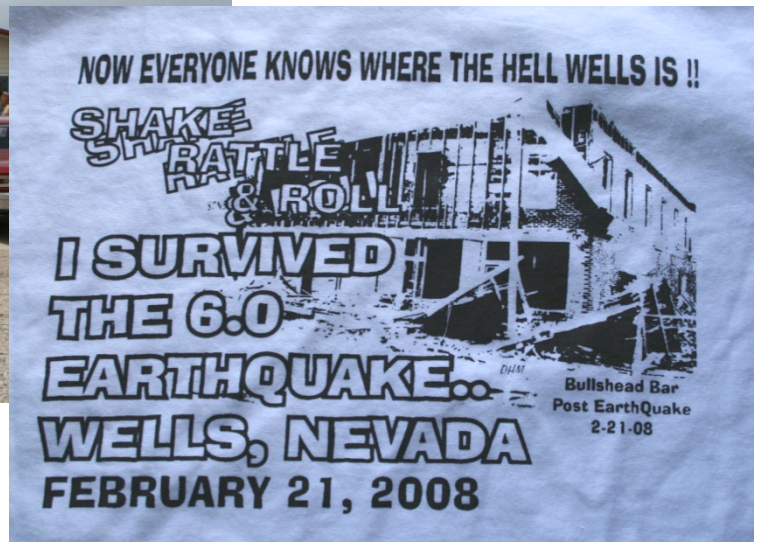
Re-establishment of Community (24 hours to 2 months)

- Getting businesses back in business
- Getting homes cleaned up and fixed
- Getting roads opened up
- Making information available to folks
- Initiating insurance procedures
- Get schooling reestablished
- Damage buildings fenced and stabilized
- Community activities (Recovery Rally)

Wells Earthquake Recovery Rally

WELLS VOLUNTEER FIRE DEPT.

Wells "Shakin' Shirts
$25.00 "Minimum" Donation
Donated by Oldies Productions
100% All proceeds donated to
Wells Disaster Relief Fund
Thank you for your support!


NOW EVERYONE KNOWS WHERE THE HELL WELLS IS !!
SHAKE RATTLE & ROLL
I SURVIVED
THE 6.0
EARTHQUAKE..
WELLS, NEVADA
FEBRUARY 21, 2008
Bullshead Bar
Post EarthQuake
2-21-08

WELLS
EARTHQUAKE
FUND
500,000
400,000
300,000
200,000

Quilici Market

Photo by G. Palmer

Intermediate Period
(months to 4 years)

- Repair and rehabilitate high school by the start of the fall semester.
- Replace damaged government buildings.
- Replace the city swimming pool.
- Moderately damaged buildings repaired.

2228

Rock House Replaced

CITY HALL

WELLS MUNICIPAL
SWIMMING POOL

Long-Term Recovery
(4 to 10 years)

- Final resolution of debris/removal of destroyed buildings.
- Clever solutions to lower costs of debris removal.
- Planning of repairs for any remaining buildings.
- Use of disaster as leverage for community funding.
- Documentation of earthquake for historical interest

4 to 6 years

- People have gotten over the earthquake – have mentally moved on.

BARGAIN BARN
S. QUILICI & SONS
SINCE 1928
09

Photo by Gerry Miller, 2015
Nine Buildings Removed
from Historical District

Common fix for damaged buildings

2015 Photo by Gerry Miller

Total Cost of the 2008 Wells Earthquake

• Emergency Response	$300,000
• Structural Damage Costs	>$7,889,000
• Nonstructural Damage Costs	>$496,000
• Content Loss Costs	$275,000
• Revenue Losses and Recovery Costs	$376,000
• Other Indirect Cost Estimates	$1,128,000

Total Cost **>$10,464,000**

Total Cost of the Wells Earthquake

Cost Category	Cost	% of Total Cost
Building damage costs	>$7,889,000	75%
Indirect cost estimates	$1,235,000	12%
Nonstructural damage costs	>$496,000	>5%
Revenue losses and recovery costs	$376,000	4%
Emergency response cost	$300,000	3%
Content loss costs	$275,000	3%
Total Costs	>$10,571,000	

Structural Damage Costs

Direct Cost Estimates

• High School Gym/Auditorium	$2,478,000
• LDS Church	>$300,000
• El Rancho	$*800,000*
• Nevada Hotel	$*500,000*
• Bullshead Bar	$*250,000*
• Wells Chalet	$*250,000*
• Seven buildings ($*80,000* ea.)	$*560,000*
• Wells City Buildings	$2,240,000

Indirect Cost Estimates

• Nevada Homeowners Disaster Assist.	$123,000
• Small Business Administration Loans	$388,000

Nonstructural Damage Costs

• 4-Way Casino (damage + contents)	$100,000
• Flying J (damage + contents)	$197,000
• Stuart Grocery	$50,000
• Wells Rural Electric	$30,000
• Bonneville Transloader	$22,000
• Four buildings $*20,000* damage ea.	$*80,000*
• Elko Co. insurance claims	$17,000
Total	**>$496,000***

(Italicized numbers were estimated)

* underestimate - some nonstructural damage repair occurred with the structural repairs and nonstructural damage occurred in other buildings.

Content Losses from the Earthquake

• 350 homes & bus. w/ $500 ea.	*$175,000*
• Stuart Grocery	$50,000
• Hardware Store	$30,000
• Great Basin Beverage Dist.	$10,000
• Two cars @ $5,000 ea	$10,000
Total	**$275,000**

(Italicized numbers were estimated)

Revenue Losses and Recovery Costs

• Loss of Business Revenues	*$175,000*
• Wells Propane (inspect + ?)	$70,000
• Insurance Adjuster (Wells)	$131,000
Total	**$376,000**

(italicized – estimated by City of Wells)

Businesses were closed for:

a few for one day,

most were closed for three days,

a couple in damaged buildings were out a few weeks,

and two businesses were lost.

Other Indirect Cost Estimates

• Donations (relief fund, recovery rally)	$258,000
• 2009 Federal Omnibus Bill	$940,000
• Private earthquake insurance	$37,000
Total	**$1,198,000**

Relief Funds/ Disaster Assistance Grants and Loans/ Earthquake Insurance Payments

• Nevada Emergency Assistance Account	$145,000
• Nevada Homeowners Disaster Assist.	$123,000
• Small Business Administration Loans	$388,000
• Donations (relief fund, recovery rally)	$258,000
• 2009 Federal Omnibus Bill (approp.)	$940,000
• Nevada Public Insurance Pool	$4,798,000
• Private Earthquake Insurance	$37,000
Total	**$6,689,000**

Relief Funds %

Relief Funding Source	Amount	% Relief	% Total Cost
Nevada Public Agency Insurance Pool	$4,798,000	72%	46%
2008 Federal Omnibus Bill	$940,000	14%	9%
Small Business Administration	$388,000	6%	4%
General Relief Donations	$148,000	2%	1%
Nevada Emergency Assistance Account	$145,000	2%	1%
Nevada Homeowners Disaster Assistance	$123,000	2%	1%
Wells Recovery Rally	$110,000	2%	1%
Private Insurance	$37,000	<1%	<1%
Total Financial Relief	$6,689,000		

Total Cost: **>$10,464,000**

Total Relief: **$6,689,000**

Relief is 64% of Costs

>$3,775,000 borne by community

Today

- Four damaged buildings left

Forward

- 2012 Building Code Adoption ("but can't check out the voice of reason – just document").
- Forward Leaning Vision.
- No hesitancy in playing the reconstruction card to get competitive community grants.
- Incorporating earthquake into Wells history.

Conclusions

- Communities should plan for recovery or there should be a state produced, generic plan.
- Recovery has to happen fast.
- Communities need support.
- Three phases: Reestablish community
  Intermediate period
  Long-term recovery

Community Recovery Actions

- Leadership and communication,
- Public dumpsters made available,
- Building Inspections,
- Fix-Up Saturdays,
- Wells Recovery Rally,
- Interfaith Group dispersed funds,
- Community Planning Assessment.

Reconstruction

- Stabilizing
- Rebuilding
- Rehabilitation

ACCEPTABLE RISK FOR SURFACE-FAULT RUPTURE IN THE BASIN AND RANGE PROVINCE

Roy J. Shlemon
P.O. Box 3066
Newport Beach, California 92659-0620
rshlemon@jps.net

ABSTRACT

Geological and engineering experience and new technology now permit construction of habitable structures across at least some so-called "active" or "hazardous" faults. This is an acceptable risk that complies with current structural engineering performance standards for all potential ground deformation except that caused by direct surface-fault rupture.

Surface-rupture risk is extremely low compared with all natural hazards in general, and with seismic risk in particular. The definition of acceptable risk is not without controversy, but to avoid all construction across any fault, regardless of the time and magnitude of the last displacement, incurs undue social and economic costs.

The Basin and Range Province is generally sparsely populated; however, significant urban agglomerations in the Reno–Carson City, Las Vegas, Salt Lake City (Wasatch Front), and the Albuquerque and El Paso areas are prone to potential surface ruptures locally exceeding ~2 m in height with horizontal accelerations potentially exceeding ~1 g. Long and variable recurrence intervals renders the typical 11.5 ka (Holocene) definition of an active fault meaningless. Here, with few exceptions, mitigation by avoidance is still prudent until such time that structural engineering design can accommodate potential surface offset and thus lower the perceived risk to a level that meets technical-community standards, codification by decision makers, and acceptance by the public.

INTRODUCTION

Are we ultra-conservative in assessing the potential for surface fault-rupture? Do we, as geologists mapping "active faults," unwittingly degrade public health, safety, and welfare by imposing our view of risk? Rhetorical questions these may be, but public welfare includes the physical and time cost of surface-rupture investigations and mitigation. Currently, such mitigation for habitable structures is usually total avoidance. Ironically, curiously exempt are most life-safety infrastructures! But geological investigations to identify and avoid any inferred "active" fault, particularly in urban environments, is often time consuming, extremely expensive, and socially disruptive (Shlemon and others, 2014).

High magnitude earthquakes do indeed cause considerable damage and often unacceptable loss of life. But most contemporary laws and related prescriptive requirements place a greater emphasis on the risk of ground rupture rather (longer recurrence interval over which the hazard must be mitigated) than on the risk of destructive high ground accelerations, the major component of general seismic risk. Seismic risk *per se*, and acceptable risk are not the same. What then, since passage of the California Alquist-Priolo Act in 1972, and in light of the many new technological advances, is the current reasonable acceptable risk for surface-fault rupture?

This paper attempts to answer these queries by:

1. Distinguishing between seismic risk, surface-rupture risk, and acceptable risk;

2. Comparing general seismic risk with other natural hazards that are traditionally identified and mitigated by engineering design; and

3. Suggesting that, where possible, structural performance, and not fault recurrence, should influence the decision to construct across potential ground-breaking faults.

NATURAL HAZARDS

Natural hazards are part of our daily existence. Seismically induced ground rupture is but one of many natural hazards that affect society in general and the Basin and Range Province in particular. Natural hazard risk is traditionally expressed as the product of the probability of an event and its consequences. As recorded throughout the world, seismic risk has, and will, cause socially unacceptable property damage and loss of life. Together, floods, hurricanes, landslides, tsunamis, and even heat and cold waves annually take thousands of lives and inflict damage in the billions of dollars.

Seismic Risk

As a natural hazard, the level of seismic risk varies with the potential number of lives lost and the related economic cost of direct damage and societal dislocation. We traditionally focus on the number and vulnerability of urban construction and related infrastructure. This is the general basis for constantly updating seismic hazard maps (Lund, 2012; National Earthquake Hazards Reduction Program [NEHRP, 2014]).

To realistically assess the risk of surface-fault rupture, general seismic risk must be put into perspective. This is illustrated by comparing the relative impact of natural hazards that produce the greatest annual mortality in the United States (figure 1). According to various data bases (SHELDUS, 1995; Borden and Cutter, 2008; Thacker and others, 2008), approximately 20,000 yearly deaths in the U.S. are directly attributable to natural disasters (Borden and Cutter, 2008). Of these, 50 percent (10,000) stem from extreme heat and old waves (Ioannou, 2013). In contrast, the average annual "geophysical-caused mortality" (earthquake, tsunami, volcanoes) is typically less than about three percent (figure 1). For the U.S., no seismic death stemmed from direct ground rupture and related structural failure. Rather, most casualties result from structural failure caused by seismically high ground accelerations, and by related liquefaction and other forms of ground deformation. Indeed, the fault generating the 1994, ~60-death, Northridge, California earthquake was centered on a blind thrust fault that produced extensive ground deformation, but no direct surface rupture (U.S. Geological Survey and Southern California Earthquake Center, 1994).

From a practical planning and design standpoint, most earthquake engineers, geologists, and architects, among others, accept that regional, high-magnitude earthquakes occur infrequently, typically with intervals more than about 100 years. Accordingly, structures are realistically built to withstand catastrophic failure stemming from estimated earthquake recurrence on the order of a hundred to perhaps a thousand years (table 1). Building codes and construction standards are based on the concept of acceptable risk, where the cost of seismically resistant construction is balanced against the chances of incurring unacceptable loss of life from future earthquakes (NEHRP, 2014).

Acceptable Risk

Acceptable risk for structural design (performance) can readily be applied to potential surface ground rupture (Bray, 2009). But what constitutes acceptable risk varies from jurisdiction to jurisdiction, and building code enforcement is often too lax or even non-existent (Slovic and Weber, 2002). Indeed, there is no shortage of definitions for seismically induced acceptable (reasonable) risk. Many definitions stem from the legal, economic, engineering, and environmental communities (Fischoff and others, 1981; Bernstein, 1998; Hunter and Fewtrell, 2001; Murphy and Gardoni, 2008). From a seismic standpoint, acceptable risk is ".... that level of earthquake effects judged to be of sufficiently low social and economic consequence, and which is useful for determining design requirements in structures or for taking certain actions" (Malhotra, 2007; Nawari, 2008). Acceptable risk is also frequently codified, and formally established by laws, codes, ordinances, and other prescriptive regulations.

Ground-Rupture Risk

Compared with all natural hazards, seismic risk is inherently low, and the probability of catastrophic structural failure from direct surface-rupture is even lower. For context, we should consider the experience and design criteria of professionals who similarly evaluate natural hazards in general and ground-rupture risk in particular. Engineers typically design structures for 100-yr, 200-yr, and even 500-yr events (table 1). Such events are inherently rare, but they do occur. From a public perspective, these are acceptable risks. Obviously, no structure, building or otherwise, is risk-free. We accept risk when crossing the street, driving an automobile, or taking any form of transportation. But most current regulations and public policy focus on total avoidance of possible surface fault rupture, assuming that such an event may occur within the next several thousand or more years. Yes it might; but how realistic is this compared with the regional impacts of other natural hazards?

For habitable structures, California and some local jurisdictions define an active fault based on probability of recurrence; that is, a fault that displays evidence of surface or near-surface displacement within about the past 11,500 years (Holocene; Bryant

and Hart, 2007; Bryant, 2010). Deterministic definitions are also applied to engineered structures, with a longer recurrence implying greater risk. Thus, 35 ka defines an active fault for design of earth-fill dams (California Division of Safety of Dams [Fraser, 2001]); about 100 ka for the once-proposed thin arch, concrete Auburn Dam (Schwartz and others, 1996); and about 500 ka for nuclear power plants, as specified in the Code of Federal Regulations (1978; Hatheway and McClure, 1979). But few, if any, structures have been catastrophically destroyed by surface-fault rupture. The impact of regional high ground shaking is orders of magnitude greater. It thus appears reasonable that, from a societal and economic viewpoint, money and professional resources can better focused on structural mitigation, rather than trying to totally avoid any potential for future surface-fault rupture, regardless of the frequency or magnitude of displacement.

FAULT-RUPTURE MITIGATION BY PERFORMANCE-BASED BUILDING DESIGN

Ideally, any habitable structure could be sited across a fault or any other plane of potential surface dislocation. This is based on performance-based building design employed by many civil, structural, and geotechnical engineers for construction of dams, bridges, and major infrastructure projects (Ghobarah, 2001; Applied Technology Council, 2006). To paraphrase Bray (2007; Bray and Dashti, 2014), a building foundation does not know what caused the ground displacement, whether it stemmed from a landslide, from liquefaction, or from surface-fault rupture. And so current professional practice allows construction, with appropriate structural mitigation, across almost any potential surface displacement except for faults! If the local geology is reasonably understood (fault recurrence, style, and displacement per event), based on site-specific and regional investigations, then habitable structures could be realistically placed across at least some hazardous faults whether the last displacement took place a few or tens of thousands of years ago (Shlemon, 2010). Present engineering design generally cannot economically mitigate surface displacements greater than perhaps several centimeters. There is, however, at least one notable exception in the Basin and Range Province; specifically, the City of Draper, Utah, where, based on the recommendation of a structural engineer, habitable structures can be designed to span Holocene faults with anticipated vertical displacement of ~2 m in certain areas (City of Draper, 2015). In general, however, such hazardous faults are still best mitigated by avoidance. Nevertheless, in certain cases, structural performance, when economically warranted, can at least locally reduce ground-rupture risk to an acceptable and reasonable level.

ACCEPTABLE SURFACE-FAULT RUPTURE RISK IN THE BASIN AND RANGE

Over 1000 Quaternary faults are known within the Basin and Range Province. Some are reasonably well documented (e.g., the Wasatch fault zone), some have apparent recurrence far exceeding ~10,000 years, and some have historically generated earthquakes with magnitudes ~7.5+ (see summaries in Pearthree and Calvo, 1987; dePolo and others, 1991; dePolo and Slemmons, 1998; Lund, 2012). Most of the Basin and Range Province is sparsely populated; however, major urban agglomerations in the Reno-Carson City and the Las Vegas area (Nevada Bureau of Mines and Geology, 1998; dePolo, 2008), along the Wasatch Front (Salt Lake City; Utah Geological Survey, 1996; Wong and others, 2002) and in the Rio Grande Rift (Albuquerque; Personius and others, 1999; Personius and Mahan, 2000) are particularly vulnerable to surface-fault rupture events that can vertically exceed ~2 m with peak horizontal accelerations exceeding 1 g. In some jurisdictions, structural mitigation is allowed where vertical displacement is not anticipated to exceed ~10 cm. In general, mitigation by current engineering design is not realistic for large fault displacements. In those cases, acceptable risk for surface-fault rupture is still avoidance by appropriate-distance setback zones, detailed geologic mapping, improved fault characterization, and a better understanding of local soil-structure interactions.

It appears that prudent but practical surface-faulting mitigation, particularly for Basin and Range Province "urban faults," is enhancement of structural design to withstand potential fault displacements up to some practical engineering limit, and to avoid catastrophic failures by avoidance when necessary, regardless of the specific fault(s) involved. This may be economically feasible for proposed new construction, but many structures built before enactment of current seismic building codes are still amenable to catastrophic failure and yet exempt from substantial retrofitting (including retrofitting to withstand strong ground motion). This is a social and economic issue long debated by engineers, geologists, planners, and others involved with the impact of natural hazards on the built environment (Nuti and Vanzi, 2003; Egbelakin and Wilkinson, 2008; Holmes, 2006).

A bold potential solution to the problem of grandfathered vulnerable structures has recently been put forth in Los Angeles where tens of thousands of existing structures were built prior to upgraded seismic building codes enacted in 1980. Although expensive and not without vocal opposition, Los Angeles will now require mandatory seismic retrofitting for the ~1000 con-

crete structures with non-ductile columns, and the many thousands of frame structures with soft story first floors, such as carports and garages. For compliance, the frame structures must be retrofitted within five years, and the concrete structures within 30 years. The cost will be borne mostly by the building owner, though business tax breaks will be made available (Lin and Xia, 2014).

SUMMARY AND CONCLUSIONS

The risk for surface-fault rupture is very low compared with the impact of natural hazards in general, and with general seismically induced ground accelerations. Surface offset by landslides or differential settlement often exceed that likely to be generated by fault displacement. Yet, many jurisdictions focus solely on surface-fault rupture and attempt to mitigate this risk by some prescriptive setback distance and by defining active faults based on some presumed probability of recurrence (e.g., Holocene) regardless of the amount of displacement in the last surface-faulting event. Telling a homeowner that the last few-centimeter surface-faulting event occurred about the time of Clovis entry into the New World (~11 ka ago), usually leads to derision of the geological community, and to ready acceptance of the consequences of any risk.

It is more practical to use the concept of acceptable risk, as defined and employed by many architects, and structural and geotechnical engineers. This concept recognizes that risk of any natural hazard is inherent, but can often be reduced to an acceptable level by appropriate engineering design. Although focusing on the impact of seismic shaking and local ground deformation, acceptable risk can be readily extended to potential construction across hazardous faults. This assumes that there is sufficient geological information, both regional and site-specific, to warrant such a decision. However, what is sufficient information? Displacement of the last event, determined from the historical or paleoseismic record, is inherently not sufficient, for there is great variability of fault slip amount and rate at any particular point on a fault. Some suggest that this problem may be overcome by averaging slip for the last three events (W.R. Lund, personal communication, January 2015); however, except for the main Wasatch fault zone, few Basin and Range Province faults are sufficiently characterized to yield such paleoseismic data. In general, where surface displacements, based on site conditions, are likely to exceed several centimeters, habitable-structure construction is not likely economically feasible and avoidance (setback) will be the most feasible mitigation.

For the Basin and Range Province, large surface-fault-rupture displacement is likely, and may, in many cases, be larger than can typically be accommodated by structural design. Recurrence intervals may be tens to hundreds of thousands of years, typically exceeding the California Holocene definition of an active fault. What then should be acceptable risk for potential construction across such faults? Based on training and perhaps on personal litigation experience, some geologists still blindly adhere to a policy of extremely low risk at any cost, and thus support avoidance of construction across faults that ruptured only once in the past ~60 to 100 ka. This would certainly offer continuous work to the geological community, but ultimately at an increased social and physical cost to land development and local and regional jurisdictions. We have learned much in the past ~45 years, especially since the 1971 Sylmar earthquake in southern California. Technological advances in engineering design and in geological knowledge now permit realistic assessment of the risk of surface-fault rupture. However, change is slow and inherently resisted, unfortunately too often to the detriment of public (Shlemon, 2010).

Potential construction across a possible active fault—as variously defined by geologists—requires above-average knowledge of the local geologic setting, performance-based design of the proposed structure, public acceptance of how safe is safe, and usually acceptance and implementation by non-technical decision-makers ostensibly based on the recommendations of the geological and engineering community. Alas, we are not there yet.

ACKNOWLEDGEMENTS

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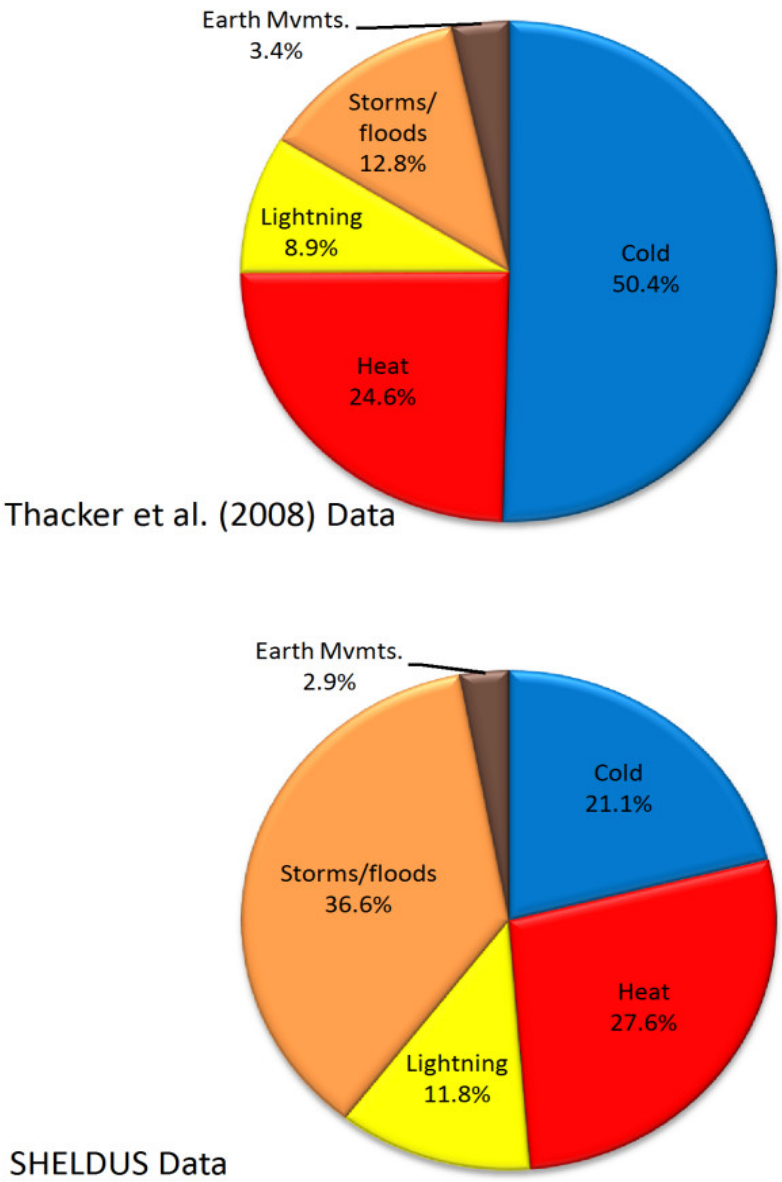


Figure 1. *Natural-hazard mortality in the United States, 1970–2004. Data from Borden and Cutter (2008), Thacker and others (2008), and Spatial Hazard Event and Loss Database for the United States (SHELDUS, 1995). Diagram from Shlemon (2010).*

Table 1. *Geologic hazards typically mitigated by engineering design based on 100 to 500-year recurrence (after Shlemon, 2010).*

Avalanche and Rock Fall	Levee Failure
Expansive Soil	Lightning
Flood	Liquefaction
Hurricane and Tornado	Subsidence
Landslide and Debris Flow	Tsunami and Storm Surge

REFERENCES

Applied Technology Council, 2006, Next-generation performance-based seismic design guidelines: Federal Emergency Management Agency, FEMA Publication 445, 127 p.

Bernstein, P.L., 1988, Against the gods: The remarkable story of risk: John Wiley & Sons, New York, NY, 383 p.

Borden, K.A., and Cutter S L., 2008, Spatial patterns of natural hazards mortality in the United States: International Journal Health Geographics, v. 7, no. 64 (electronic document available at http://www.ij-healthgeographics.com/content/7/1/64).

Bray, J.D., 2009, Designing building to accommodate earthquake surface fault rupture: Applied Technology Conference and Structural Engineering Institute, American Society of Civil Engineers, 2009 Conference on improving the seismic performance of existing buildings and other structures, p. 1269-1280.

Bray, J.D., and Dashti, S., 2014, Liquefaction-induced building movements: Bulletin of Earthquake Engineering, Springer, v. 12, no. 3, p. 1129-1156.

Bryant, W.A., 2010, History of the Alquist-Priolo earthquake fault zoning act, California, USA: Environmental & Engineering Geoscience, v. XVI, no. 1, p. 7-18.

Bryant, W.A., and Hart, E.W., 2007, Fault-rupture hazard zones in California: California Geological Survey Special Publication 42 (revision 2007), 42 p.

City of Draper, 2015, City of Draper, Utah Municipal Code, Geologic Hazards Ordinance, Title 9, Chapter 19, accessed online at www.sterlingcodifiers.com/codebook/index.php?book_id=1002.

dePolo, C.M., 2008, Quaternary faults in Nevada, Nevada Bureau of Mines and Geology, Map 167, scale 1:1,000,000.

dePolo, C.M., Clark, D.G., Slemmons, D.B., and Ramelli, A.R., 1991, Historical surface faulting in the Basin and Range Province, western North America—Implications for fault segmentation: Journal of Structural Geology, v. 13, no 2, p. 123-136.

dePolo, C.M. and Slemmons, D.B., 1998, 130,000 year vs. 10,000 year (Holocene) classification of active faults in the Basin and Range province, *in* Lund, W. R. (editor), Proceedings: Basin and Range Province Seismic-Hazards Summit: Utah Geological Survey Miscellaneous Publication 98-2, p. 37-38.

Egbelakin, T., and Wilkinson, S., 2008, Factors affecting motivation for improved seismic retrofit implementation, Australian Earthquake Engineering Conference, 10 p., accessed online at www.academia.edu/906372/factors_affecting_motivation_for_improved_seismic_retrofit_implementation.

Fischoff, B., Lichtenstein, S., Slovic, P., Derby, S.L., and Keeney, R., 1981, Acceptable risk: Cambridge University Press, Cambridge, United Kingdom, 185 p.

Fraser, W.A., 2001, California Division of Safety of Dams fault activity guidelines: California Division of Safety of Dams, Sacramento, California, 11 p., accessed online at www.water.ca.gov/damsafety/docs/fault.pdf.

Ghobarah, A., 2001, Performance-based design in earthquake engineering—State of development: Engineering Structures, v. 23, no. 8, p. 878-884.

Holmes, W.T., 2006, Risk Management Series: Designing for Earthquakes – A manual for architects: Federal Emergency Management Agency (Washington, DC), Chapter 8, p. 8-1 – 8-74.

Hunter, P.R., and Fewtrell, L., 2001, Acceptable risk, *in* Fewtrell, L, and Bartram, J., editors, World Health Organization (WHO), Water Quality Guidelines, Standards and Health, Chapter 10: London, IWA Publishing, United Kingdom, p. 207-227.

Ioannou, P., 2013, Heat waves in the United States: Cyprus International Institute and Harvard School of Public Health, 10 p.

Lin, R.G, and Xia, R., 2014, Los Angeles, 8 December 2014; accessed online at www.latimes.com/local/lanow/la-me-In-earthquake-safety-retrofit., 4 p.

Lund, W.R., editor, 2012, Recommendations to the U.S. Geological Survey National Seismic Hazard Mapping Program for the 2014 update of the National Seismic Hazard Maps: Utah Geological Survey Open-File Report 591, 17 p., x appendices.

Malhotra, P.K., 2007, Seismic hazard analysis for building codes: Seismological Research Letters, v. 78, no. 4, p. 415-416.

Murphy, C. and Gardoni, P., 2008, The acceptability and the tolerability of societal risks—a capabilities-based approach: Science Engineering Ethics, v. 14, no. 1, p. 77-92.

Nawari, N.O., 2008, Foundation design against progressive collapse of buildings: Geotechnical Special Publication, v. 178, p. 947-954.

National Earthquake Hazards Reduction Program, 2014, accessed online at www.nehrp.gov/

Nevada Bureau of Mines and Geology, 1998, Guidelines for evaluating potential surface fault rupture/land subsidence hazards in Nevada: Nevada Bureau of Mines and Geology, Reno, Nevada, accessed online at www.nbmg.unr.edu.

Nuti, C., and Vanzi, I, 2003, To retrofit or not to retrofit?: Engineering Structures, v. 25, p. 701-711.

Pearthree, P.A., and Calvo, S.S., 1987, Evidence for large magnitude earthquakes with very long recurrence intervals, Basin and Range Province of southeastern Arizona: Bulletin of the Seismological Society of America, v. 77, no. 1, p. 97-116.

Personius, S.F., Machette, M.N., and Kelson, K.I., 1999, Quaternary faults in the Albuquerque area—An update: New Mexico Geological Society Guidebook, 50th Field Conference, Albuquerque, New Mexico, p. 189-200.

Personius, S.F., and Mahan, S.A., 2000, Paleoearthquake recurrence on the East Paradise fault zone, metropolitan Albuquerque, New Mexico: Bulletin of the Seismological Society of America, v. 90, no. 2, p. 357-369.

Schwartz, D.P., Joyner, W.B., Stein, R., Brown, R.D., McGarr, A.F., Hickman, S.H., and Bakun, W.H., 1966, Review of seismic-hazard issues associated with the Auburn Dam project, Sierra Nevada foothills, California: U. S. Geological Survey Open-File Report 96-0011, accessed online at http://pubs.usgs.gov/of/1996/of96-011.

Shlemon, R.J., 2010, A proposed mid-Holocene age definition for hazardous faults in California: Environmental & Engineering Geoscience, v. XVI, no. 1, p. 55-64.

Shlemon, R.J., Kolthoff, S.H., and Reader, M., 2014, The Hollywood fault; Where is it?: AEG News (Association of Engineering Geologists), Annual Meeting Program with Abstracts, v. 57, p. 77, Scottsdale, Arizona.

Slovic, P., and Weber, E.U., 2002, Perception of risk posed by extreme events: Conference on Risk Management Strategies in an Uncertain World, Palisades, New York, 21 p.

Thacker, M.T., Lee, R., Sabogal, R.I., and Henderson, A., 2008, Overview of deaths associated with natural events, United States, 1979-2004: Disasters, v. 32, no. 2, p. 303-315.

U.S. Geological Survey and the Southern California Earthquake Center [Scientists of], 1994, The magnitude 6.7 Northridge, California, earthquake of 17 January 1994: Science, v. 266, p. 389-397.

Utah Geological Survey, 1996, The Wasatch fault: Utah Geological Survey Public Information Series 40, 17 p.

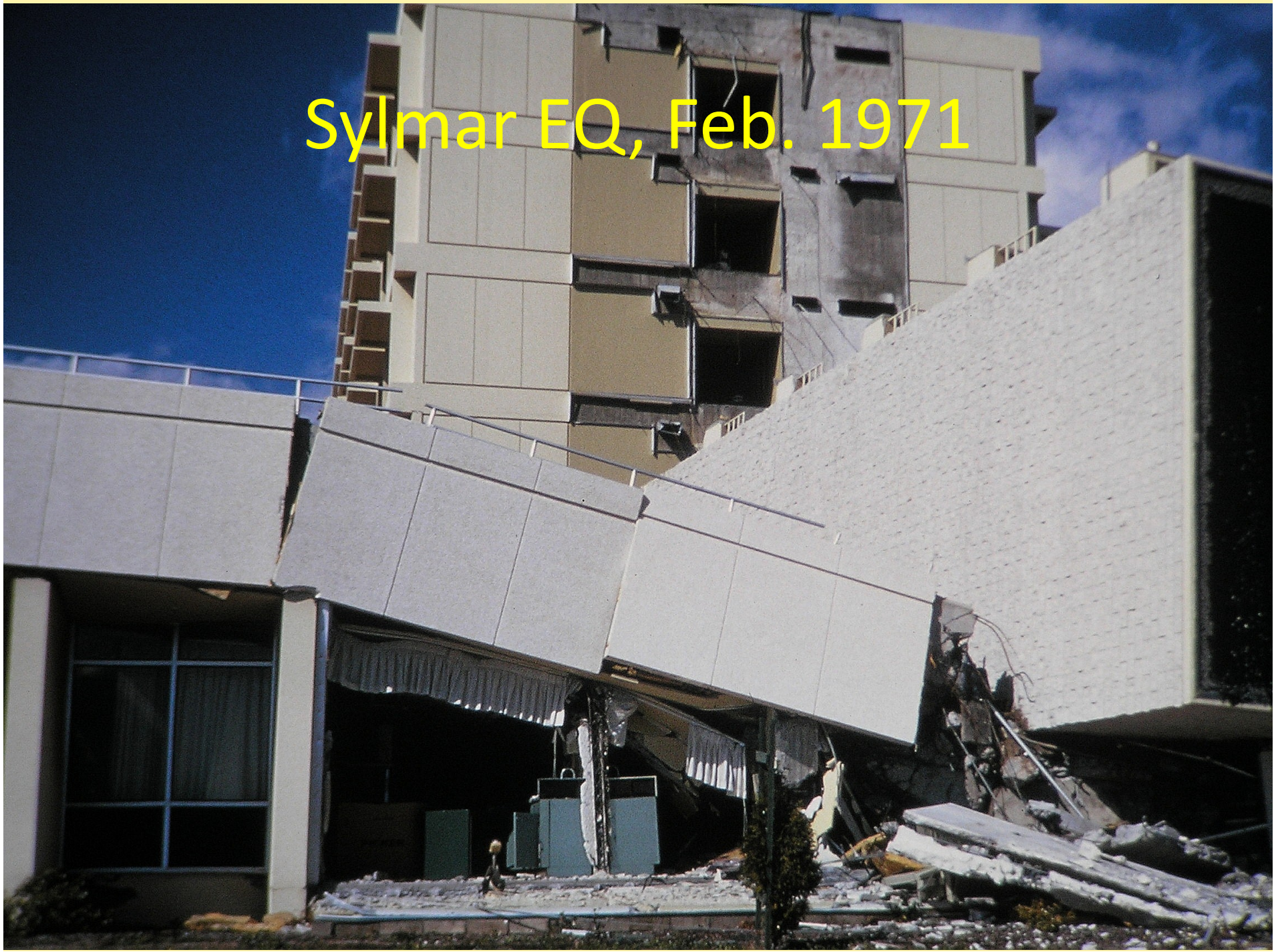
Wong, I., Silva, W., Wright, D., Olig, S., Ashland, F., Gregor, N., Christenson, G., Pechmann, J., Thomas, P., Dober, M., and Gerth, R., 2002, Ground-shaking map for a magnitude 7.0 earthquake on the Wasatch fault, Salt Lake City, Utah, metropolitan area: Utah Geological Survey Public Information Series 76, scale 1:24,000.

The following is a PDF version of the author's PowerPoint presentation.

ACCEPTABLE RISK FOR SURFACE FAULT RUPTURE IN THE BASIN AND RANGE

- Roy J. Shlemon
- Newport Beach, CA

- BRPSHSIII – Salt Lake City
- January 2015


Sylmar EQ, Feb. 1971

Please check the DMG web site (http://www.consrv.ca.gov/dmg/) to obtain the current edition of this document.

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Supplements 1 and 2 added 1999

FAULT-RUPTURE HAZARD ZONES IN CALIFORNIA

Alquist-Priolo Earthquake Fault Zoning Act
with Index to Earthquake Fault Zones[1] Maps

[1] Name changed from Special Studies Zones January 1, 1994

Note: The digital version of this document differs slightly from the current printed edition of SP 42. (1) It includes supplements 1 and 2; (2) map indexes 4a through 4g have been updated to include the maps released through 1999. However, the lists of affected cities and counties and other information contained in this file have not been altered. Also, the new address and phone number of DMG's Los Angeles office is noted on the supplements.

DEPARTMENT OF CONSERVATION
Division of Mines and Geology

THE RESOURCES AGENCY
MARY NICHOLS
SECRETARY FOR RESOURCES

STATE OF CALIFORNIA
GRAY DAVIS
GOVERNOR

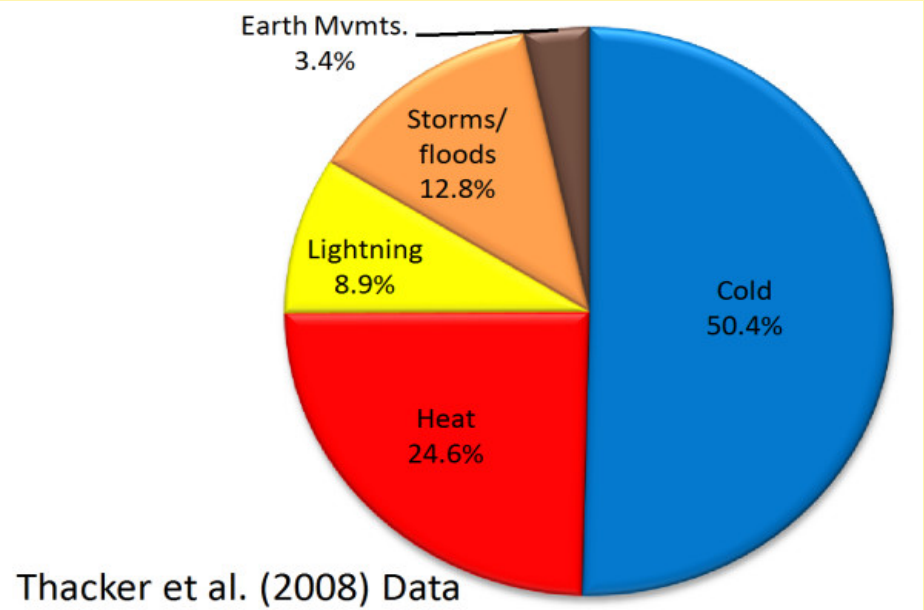
DEPARTMENT OF CONSERVATION
STEVE ARTHUR
ACTING DIRECTOR

Lessons Learned Since 1972

- Active fault, surface rupture initially 10 k bp
- Evolved to 11.5 ka, Pleistocene-Holocene transition.
- Locally now ~13 ka based on calibrated radiocarbon years (hence ~ 30 percent increase in regulatory interpretation.
- No loss of life from ground rupture; but hundreds of death from structural collapse.

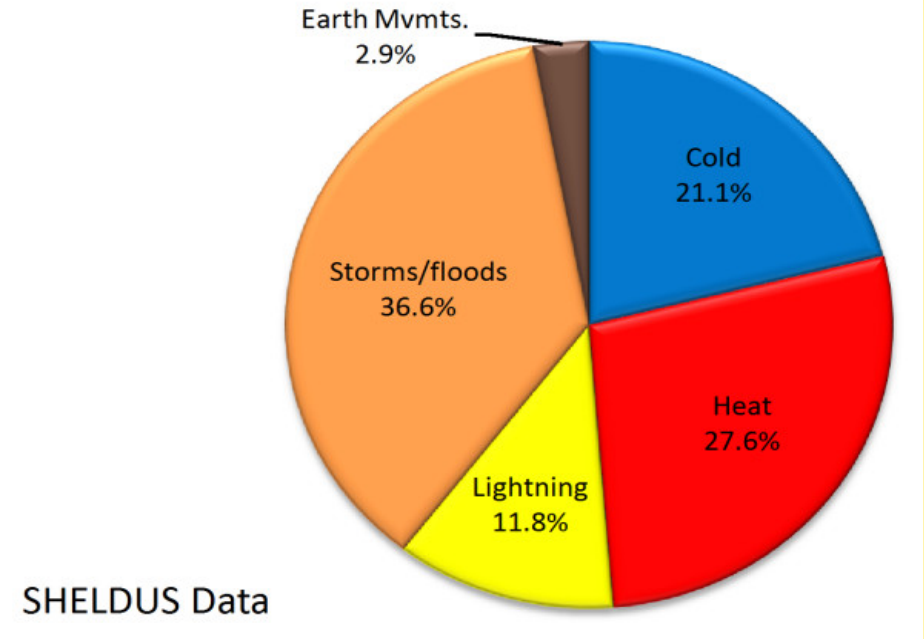
Natural Hazards - Acceptable Risk
100 - 500 years

- Floods
- Hurricanes
- Tornados
- Landslides
- Rock falls
- Tsunamis
- Avalanches
- Lightning
- Levee Failures
- Solar Flares
- Fault ground-rupture = 11.5 ka!



Thacker et al. (2008) Data

From Borden and Cutter, 2008



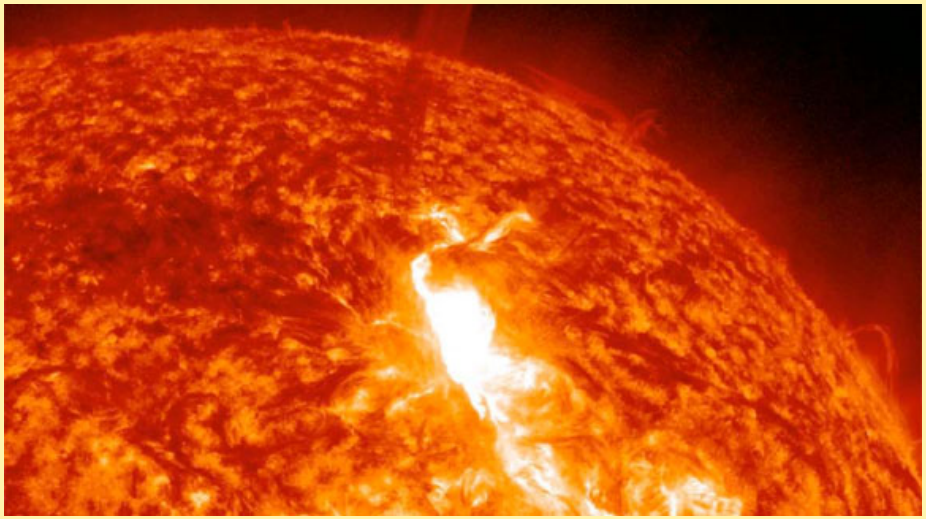
SHELDUS Data

Active/Hazardous Faults

- **Mitigation solely by avoidance**
- **Surface or near-surface ground rupture in last ~11.5 ka**
- **11.5 ka C-14 years = ~13.5 ka calibrated yrs; = >Clovis culture (Younger Dryas) in the New World!**
- **If not performance-based mitigation, why not ~4- 6 ka? Still ultra conservative.**

- ***Perspective*: Natural hazard mortality in US by event:**
  - **Heat and cold ~57 percent**
  - **Storms/floods ~30 percent**
  - **Lightning ~10 percent**
  - **Earth movement ~3 percent**

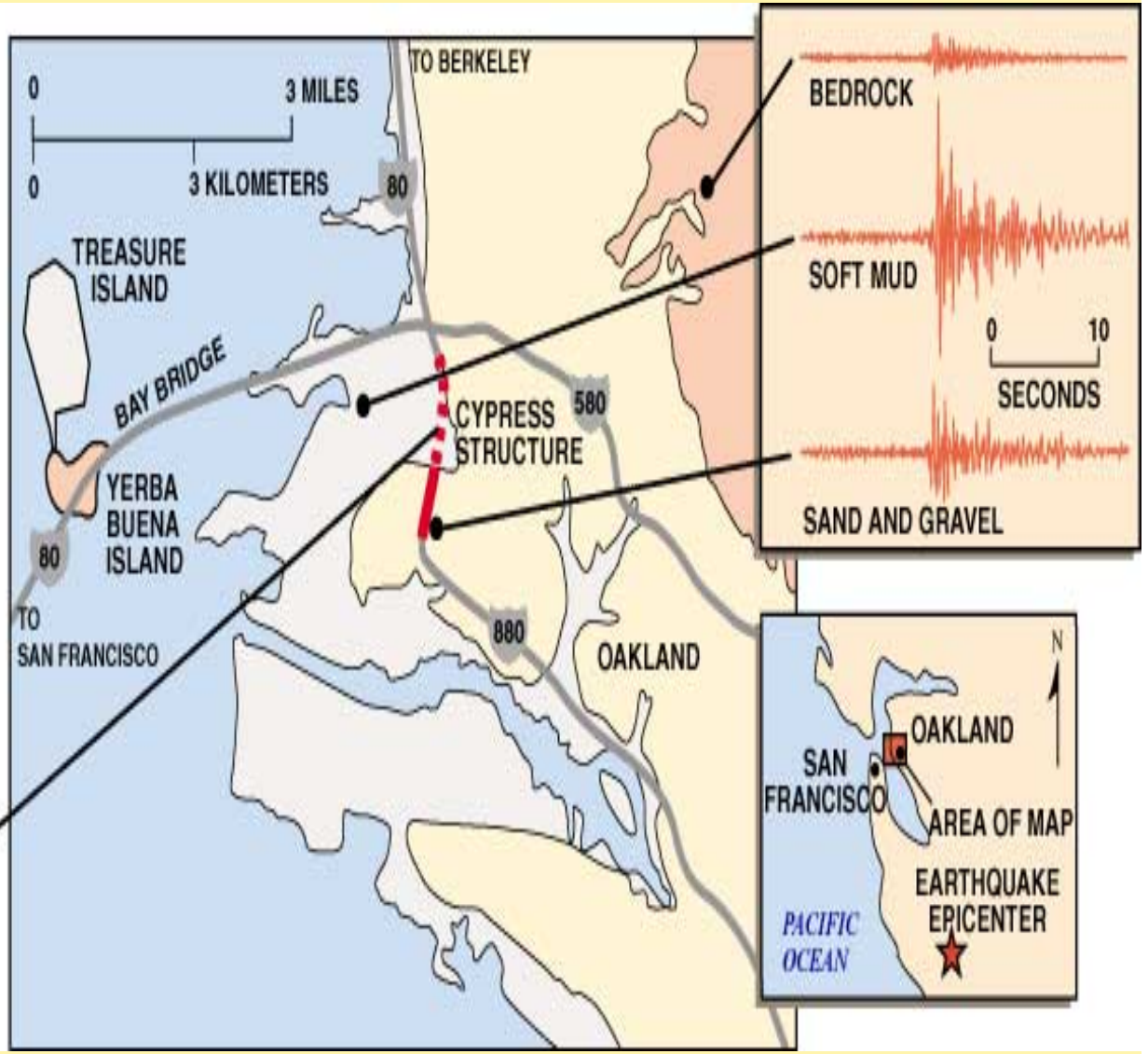
A solar flare erupts on January 22, 2012 (Credit: NASA Images)



Carrington Event of 1859 (Super Solar Flare); Solar Cycle 10

Richard C. Carrington, British Amateur Astronomer observed major coronal mass ejection (CME) travel to earth in 17 hours (normally takes 3-4 days). Auroras seen throughout the world, as far south as the Caribbean and Hawaii; disrupted telegraph communication.

Greenland ice cores record similar high-energy proton radiation events every ~ 500 years; lesser storms occurred in 1921, 1960 and 1972 (Quebec) disrupting power systems and radio communications.


0
3 MILES
0
3 KILOMETERS
TO BERKELEY
80
TREASURE ISLAND
BAY BRIDGE
YERBA BUENA ISLAND
80
TO SAN FRANCISCO
CYPRESS STRUCTURE
580
880
OAKLAND
BEDROCK
SOFT MUD
0
10
SECONDS
SAND AND GRAVEL
N
OAKLAND
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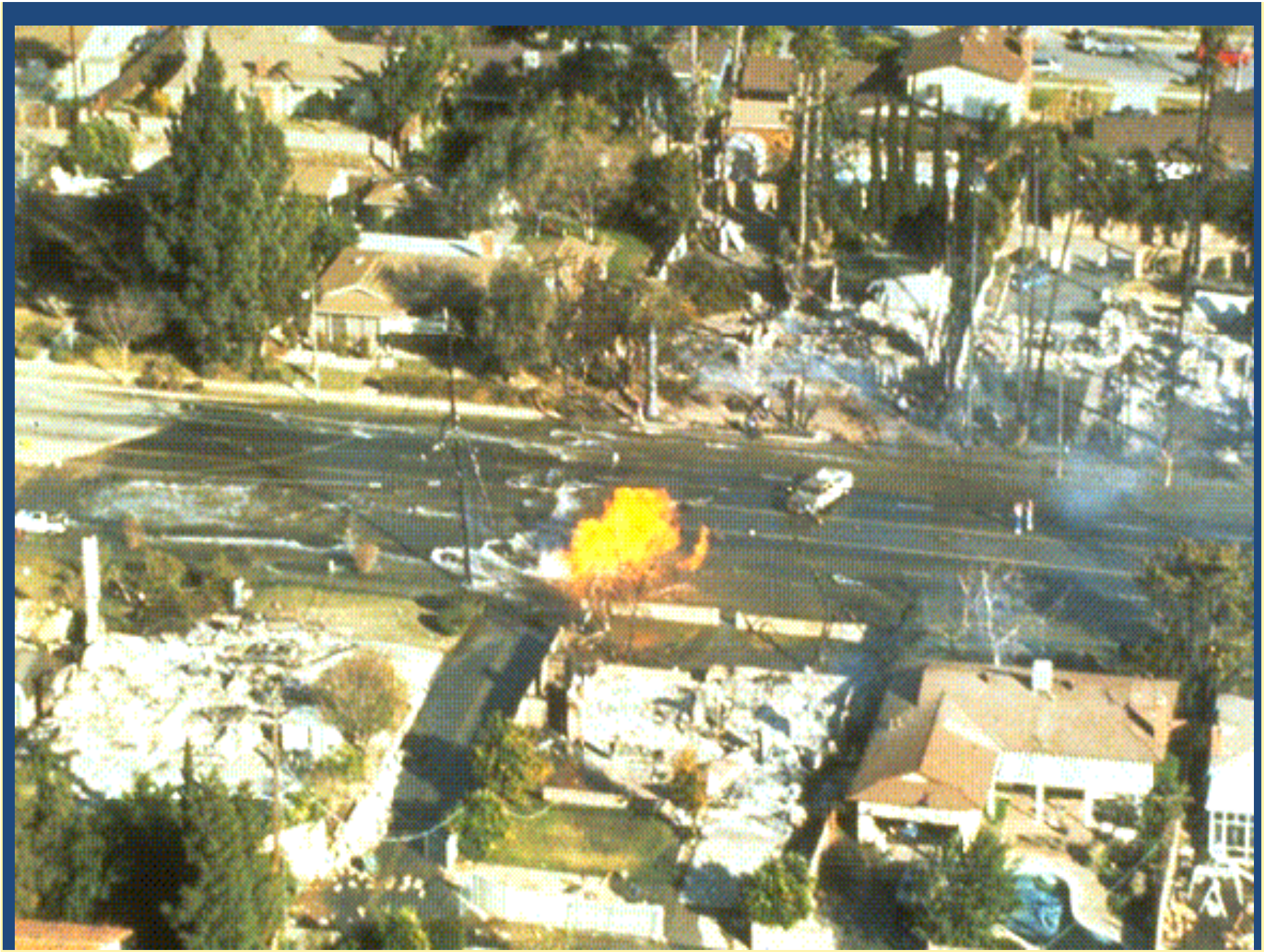
AREA OF MAP
EARTHQUAKE EPICENTER
PACIFIC OCEAN

7 18'94



Risk Is Acceptable When:

- It falls below an arbitrary probability;
- It falls below some level that is already tolerated;
- The cost of risk reduction exceeds costs saved, including “costs of suffering;”
- *Professionals say it is acceptable;*
- The general public say it is acceptable (or, more likely, that it is not acceptable).
- Politicians say it is acceptable.

What is Acceptable Risk for Surface-Fault Rupture?

- Most contemporary laws and prescriptive requirements focus on surface-fault rupture rather than on high ground accelerations, the major component of general seismic risk (e.g. CA AP active-fault definition, zoning and setback requirements).

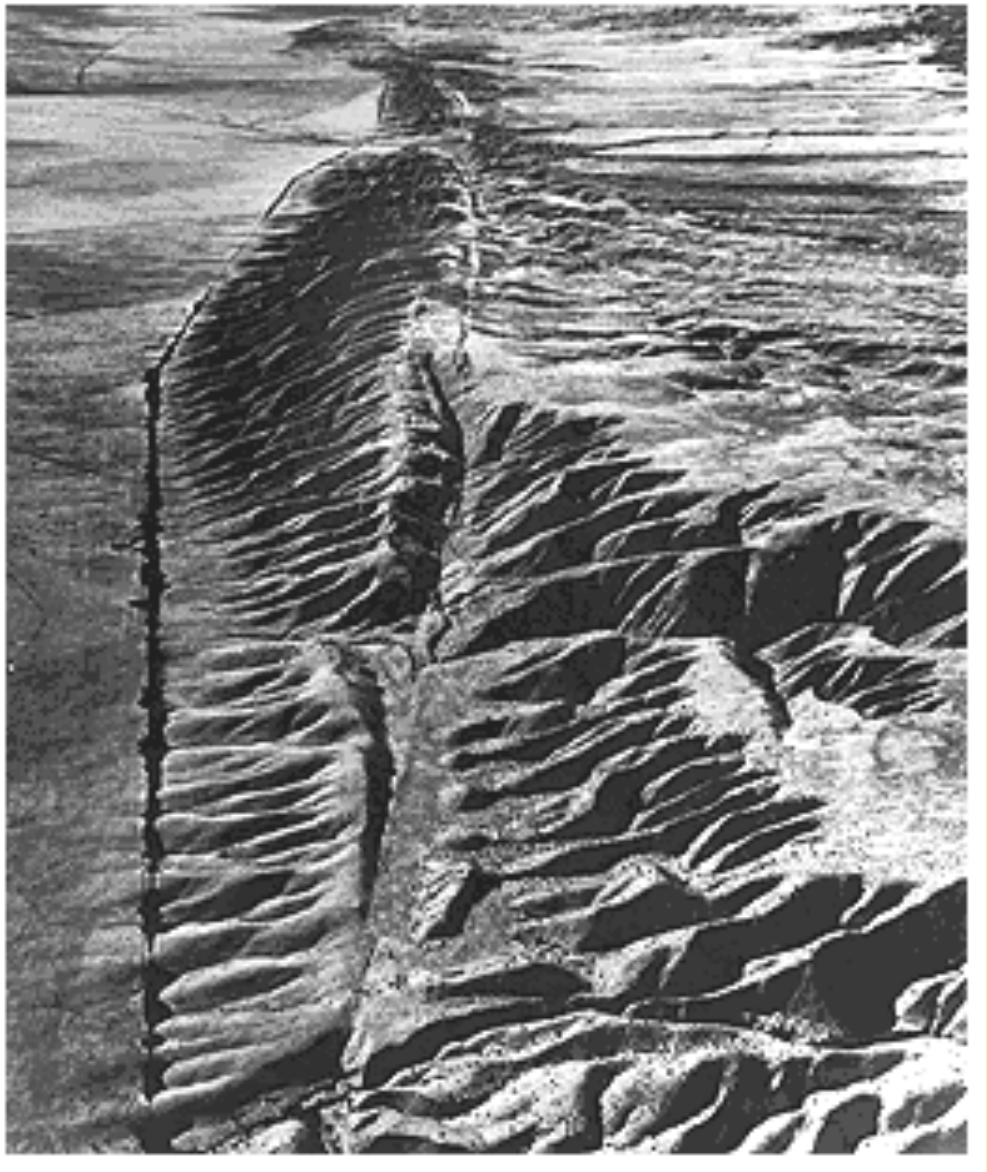
- Seismic risk, *per se,* and acceptable risk are not the same.

- Concept of Acceptable Risk: Absolute safety is an unachievable goal. Seismically, acceptable risk = *that level of earthquake effects judged to be of sufficiently low social and economic consequence, and useful for determining design requirements or for taking certain actions*.

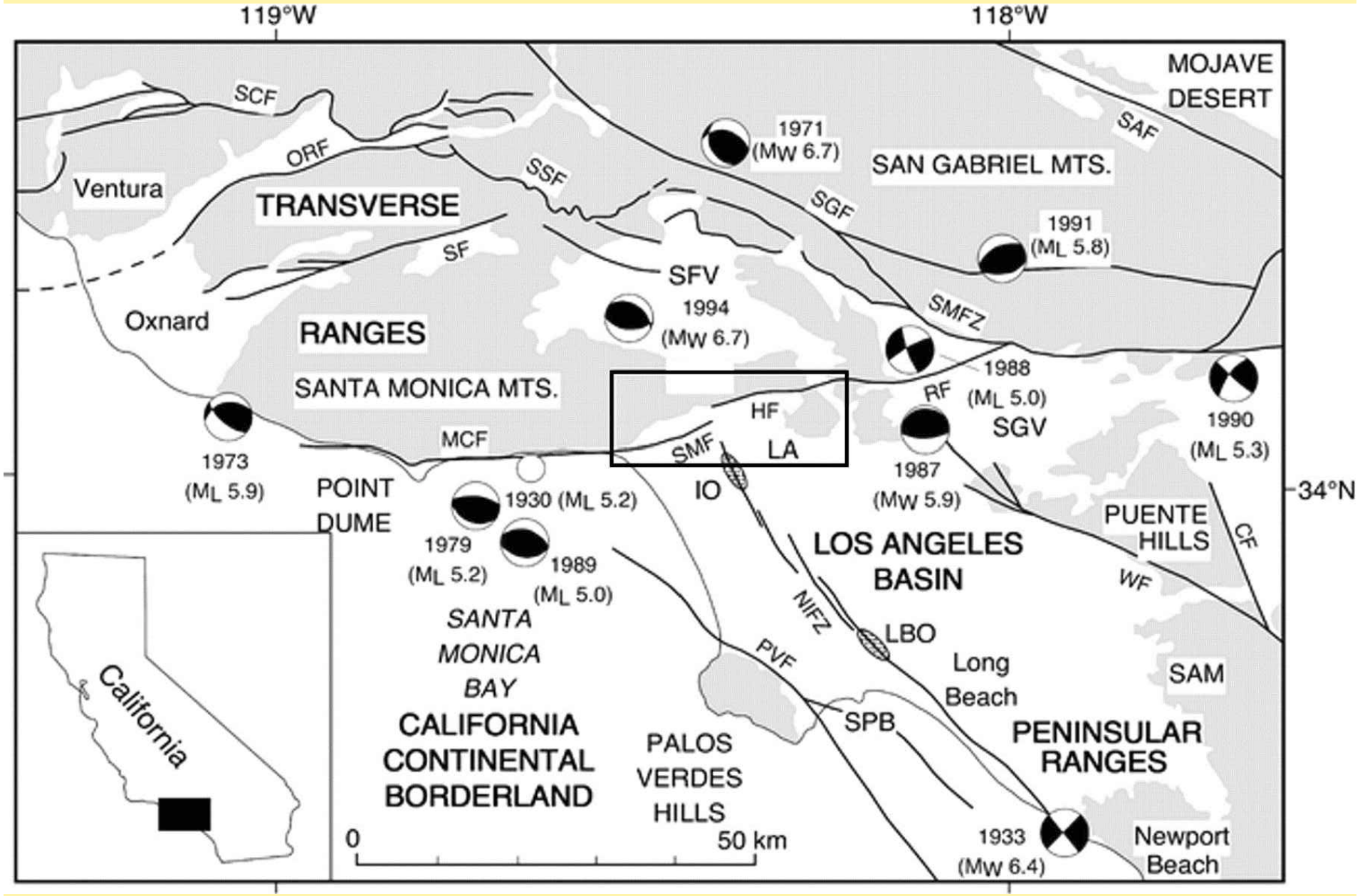
- Practical mitigation is performance-based building design applicable to all natural hazards except surface-fault rupture!

B&R SURFACE-FAULT RUPTURE

- 1000 + Q faults in the BR; ~250 with latest Pleistocene/Holocene activity.
- EQ magnitudes >7.5; vertical ground displacements > 2 m., peak horizontal accelerations > 1 g.
- Urban agglomerations = highest risk (e.g., SLC/Wasatch front; Reno/ Carson City; Las Vegas; Albuquerque; El Paso).
- Structural performance mitigation acceptable for life-safety infrastructure and all natural hazard risks; but not for surface fault rupture! Why?
- Current engineering mitigation for some Wasatch Front communities: up to ~10 cm vertical displacement. Elsewhere, total avoidance (setback) from Holocene (11,500-yr) faults following CA AP criteria.



CAPITOL RECORDS


119°W
118°W
34°N
MOJAVE DESERT
SAF
SCF
ORF
SSF
SGF
SAN GABRIEL MTS.
1971 (MW 6.7)
Ventura
TRANSVERSE
RANGES
SF
SFV
1994 (MW 6.7)
1991 (ML 5.8)
SMFZ
Oxnard
SANTA MONICA MTS.
HF
RF
1988 (ML 5.0)
SGV
1990 (ML 5.3)
1973 (ML 5.9)
MCF
SMF
LA
1987 (MW 5.9)
POINT DUME
1930 (ML 5.2)
IO
PUENTE HILLS
CF
1979 (ML 5.2)
1989 (ML 5.0)
LOS ANGELES BASIN
WF
NIFZ
SANTA MONICA BAY
LBO
PVF
Long Beach
SAM
SPB
CALIFORNIA CONTINENTAL BORDERLAND
PENINSULAR RANGES
PALOS VERDES HILLS
1933 (MW 6.4)
Newport Beach
California
0
50 km

SUMMARY

- **Acceptable Risk = concept used by architects, and structural and geotechnical engineers for structural performance design; reduce risk to an acceptable level. Practical, and understandable; so why not for potential surface-fault rupture?**

- **Mitigation criteria are flexible, change with time, based on new geological knowledge and engineering advances.**

- **We have learned much in the past 43 yrs. Why do we still cling to the deterministic ~11,500-yr definition for an active/hazardous fault? Time to consider structural performance for mitigation.**

- **Suggested changes will likely provoke regulatory angst; but now is the time for serious change!**

BUILDING POLICY CONSIDERATIONS IN SEISMICALLY VULNERABLE AREAS OF THE BASIN AND RANGE PROVINCE

Ron Lynn
Clark County, Nevada Department of Development Services
4701 West Russell Road, Las Vegas, Nevada 89118-2231
rll@clarkcounty.gov

Throughout recorded history there is evidence of humanity working together and sometimes struggling in an effort to overcome adversity. We have systematically adapted our standards of living to take advantage of our accumulated knowledge and command of technology. Early humans lived a primitive existence and were relegated to seeking shelter in whatever form nature had to offer. From this humble beginning, we learned to create shelter by constructing simple tents and lean-to shelters. As knowledge and understanding grew, so did our ability to create more elaborate shelters of wood, mud, rock, and other readily available natural materials. We continue our quest for shelter by utilizing manufactured building materials such as brick, block, cut and processed wood, concrete, and steel. We progress further by improving weather tightness and by adding amenities such as indoor plumbing, electricity, and air conditioning. The cumulative effect of all of these improvements is that we have greatly improved our living conditions in areas such as basic health, sanitation, and even safety. The down side to all of this improvement is that we now invest a more substantial amount of effort into the construction and maintenance of the buildings that shelter us. By creating better and more elaborate buildings, we have also placed some of the fruits of our labors at greater risk by not paying attention to the thoughts, habits, and mistakes of our ancestors. If a primitive shelter was damaged or destroyed, it could be repaired or a new one constructed with minimal additional effort. Our modern shelters are not so readily repaired or replaced, so it is all the more important that we make good decisions with respect to how and where we build. Perhaps our next great contribution to improving our standards of living is to recognize that we are still very much dependent upon nature, and we should give more consideration to minimizing the impact of natural hazards on our buildings.

Data has long been available to scientists, engineers, and public officials concerning high-hazard impacts to our communities. Regions of subsidence, expansive clays, sink holes, flood prone areas, faults, and land susceptible to wildfire have been identified, mapped, scrutinized, and evaluated. The negative effects associated with natural conditions are very real and have been well documented. Disasters have occurred resulting in loss of life and trillions of dollars in damage. Yet we continue to build in areas that put our communities at risk, and ignore the life safety consequences of permitting vulnerable structures to exist and be inhabited.

There is an old adage that building codes are written in blood. In other words, it takes a disaster of significant magnitude to change public opinion to implement new laws that modify our behavior. We have amassed great bodies of knowledge, so it is not the failing of science or engineering. Perhaps we as scientists and engineers have failed to adequately spread our knowledge so that others may someday benefit from its use…

In the Basin and Range Province states, the fact remains that there is very little legislation that requires the identification of high-risk structures, their evaluation, and eventual remediation. This, coupled with very limited land-use restrictions on building in seismically impacted areas, almost assures a disaster will impact our communities. With very few exceptions, we do not plan for the future, we react to events.

Multiple organizations including the Structural Engineers Association of Northern California, Federal Emergency Management Agency, and the United States Resiliency Council have published documents identifying types of buildings that are of highest risk in a seismic event including unreinforced masonry, non-ductile concrete frame buildings, soft story construction, as well as others. The policy question is why are we not labeling such buildings, or restricting their use in occupancy, or requiring their remediation or removal?

Further, there are detailed fault maps in many urban areas, but we continue to build over these faults or within their expected impact areas. Why? The why is the public-opinion process. No matter how good the engineering, no matter how sound the science, if we cannot convince the policymakers that things must change, all we have produced is a series of good ideas. The question for all of us is how we modify our actions to change the behavior of policymakers in our communities and states.

The following is a PDF version of the author's PowerPoint presentation.

Building Policy Considerations in Seismically Vulnerable Areas of the Basin Range

Ronald L. Lynn
Director/Building & Fire Official
Clark County Building & Fire Prevention

WHAT IS OUR CHALLENGE?

HOW DO WE EFFECT CHANGE TO CREATE A BETTER ENVIRONMENT FOR OUR COMMUNITIES?

WHAT IS OUR CHALLENGE?

- Public acceptance
- Human perception
- Need and Demands
- Enlightened self interest
- Political process

SCIENCE

- Geology
- Geophysics
- Geodetics
- Mapping

ENGINEERING

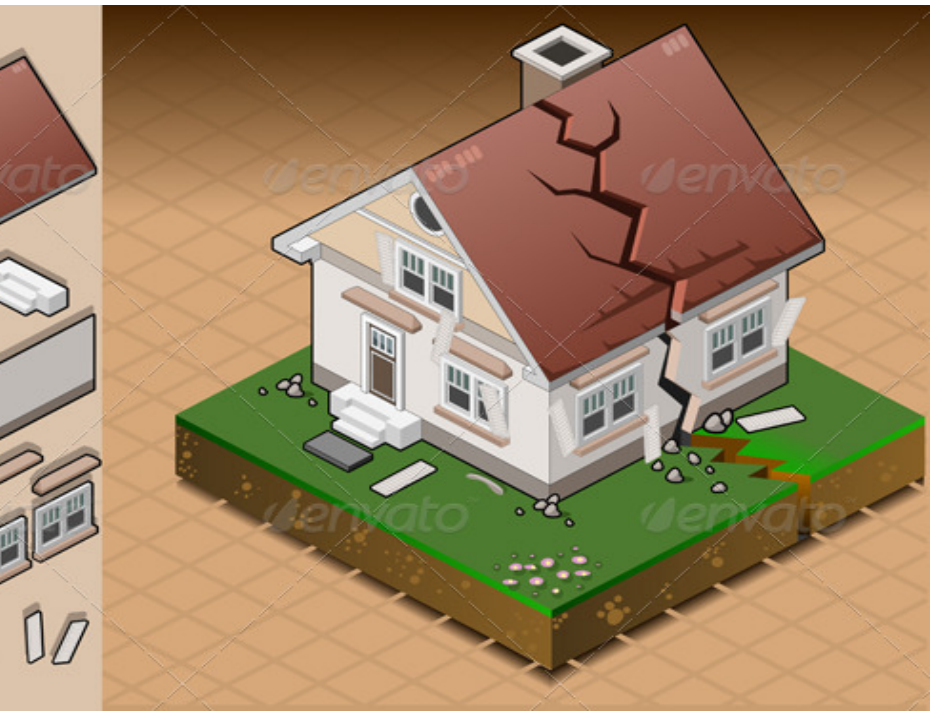
- Materials
- Stress strain analysis
- Strength
- Stiffness
- Ductility
- Performance based design

WHAT DO WE DO?

Legislation: Enacting laws –not good ideas

- Fault setbacks
- Identify vulnerable structures
- Rating buildings
- Adopting building codes

Fault Setbacks



- Alquist-Priolo
- Clark County, Nevada fault setback requirements

DEFINING VULNERABLE ELEMENTS

- URM's
- Soft story construction
- Non-ductile concrete frame buildings
- URM Chimneys
- Parapet Walls
- Signs and attachments

NOVELL
BAIL BONDS
BlueLine Rental
TRI-CITY
FENCE COMPANY

TRI-CITY
FENCE COMPANY
STOP

816
TRI-CITY
FENCE COMPANY
510-758-4954
707-644-5764
TRI-CITY
FENCE COMPANY

Heavily damaged apartment building, Reseda. The building has collapsed onto its structurally weak first story, partially crushing several parked cars. This type of damage was common in the epicentral region; partially open first-story levels have poor resistance to strong, horizontal ground motion. The piles of debris and the destruction on the left are the results of a fire that broke out after an aftershock. Photograph by J. W. Dewey.

DO NOT ENTER

Wells, Nevada
CLOSED

Rating Buildings

Provides an objective methodology for assessing building performance
Is technically credible within the engineering community
Clearly communicates building performance to all stakeholders
Becomes a vital component of real estate transactions
Can be used by owners and tenants to make rational risk management decisions
Provides market forces to upgrade seismically deficient buildings

Safety Rating	
	Injuries and blocking of exit paths unlikely Expected performance results in conditions unlikely to cause injuries or to keep people from exiting the building.
	Serious injuries unlikely Expected performance results in conditions that are unlikely to cause serious injuries.
	Loss of life unlikely Expected performance results in conditions that are unlikely to cause loss of life.
	Loss of life possible in isolated locations Expected performance results in partial collapse or falling objects which have a potential to cause loss of life at some locations within or around the building.
	Loss of life likely in the building Expected performance results in building collapse which has a high potential for deaths of people who are in or around the building.

U.S. Resiliency Council - http://www.usrc.org/rating-definitions

Repair Cost Rating

	Minimal Damage Repair Cost likely less than 5% of building replacement cost.
	Moderate Damage Repair Cost likely less than 10% of building replacement cost.
	Significant Damage Repair Cost likely less than 20% of building replacement cost.
	Substantial damage Repair Cost likely less than 40% of building replacement cost.
	Severe Damage Repair Cost likely greater than 40% of building replacement cost.
NE	**Not Evaluated** This dimension has not been evaluated.

U.S. Resiliency Council - http://www.usrc.org/rating-definitions

Time to Regain Basic Function Rating	
	Within hours to days. The expected performance will likely result in people being able to quickly re-enter and resume use of the building from immediately to a few days, excluding external factors.
	Within days to weeks The expected performance may result in delay of minimum operational use for days to weeks, excluding external factors.
	Within weeks to months The expected performance may result in delay of minimum operational use for weeks to months, excluding external factors.
	Within months to a year Expected performance may result in delay of minimum operational use for months to a year.
	More than one year Expected performance may result in delay of minimum operational use for at least one year or more.
NE	**Not Evaluated** This dimension has not been evaluated.

L.A. mayor calls for mandatory earthquake retrofitting for thousands of buildings

Los Angeles Times

December 8, 2014

THE MISSION

Initiate change for the future, as well as enhance our existing building stock to drive our community's resilience, safety, sustainability and welfare.

Sprinkles

Harrah's

10

ACKNOWLEDGEMENTS

I would like to express my appreciation for the following individuals and institutions who provided valuable information for this presentation:

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- University of Nevada, Reno
- US Resilience Council

MITIGATING SURFACE FAULTING: DEVELOPING AN EARTHQUAKE FAULT ZONING ACT FOR THE NEW MILLENNIUM

Eldon Gath
Earth Consultants International, 1642 E. 4th Street, Santa Ana, California 92705
gath@earthconsultants.com

ABSTRACT

Following the 1971 San Fernando earthquake, enactment of the Alquist-Priolo (A-P) "Earthquake Fault Zoning Act" in 1972 initiated an important program to mitigate surface-faulting hazard in California. The legislative intent of the act was to prohibit most new structures intended for human occupancy from being built across active faults (defined as a fault which has had surface displacement in Holocene time [about the past 11,000 years]) to avoid fault-rupture hazards in future earthquakes. While progressive for its time, the A-P Act has become a 40-year old law in need of revision and modernization to reflect the four decades of improved knowledge about fault hazards and earthquake engineering of soils and structures since its adoption. When the A-P Act was first enacted, the science of paleoseismology was not yet established, and few geologists understood or could realistically quantify the fault-rupture process, much less its temporal and spatial predictability. Today, many geologists specialize in this field, and have the skills to quantify discrete coseismic fault displacements. Engineers now routinely provide practical performance-based structural mitigation alternatives for other kinds of ground-displacement hazards (e.g., landslides and mining subsidence), in contrast to the current policy of fault avoidance, regardless of displacement, recurrence, or kinematics for surface-faulting mitigation.

The public, and the geologic and engineering professions are better served by upgrading fault-zoning laws for consistency with the risks accepted for other natural hazards. It is herein proposed to replace the A-P defined "active fault" term for residential development, currently reflecting any amount of Holocene-age surface rupture, with "hazardous fault," defined as a fault with movement within 500 years of its average recurrence interval or already past it. This definition is consistent with the 10% probability of exceedance in 50 years depicted on current U.S. Geological Survey (USGS) seismic-hazard maps and used in most residential building codes. For higher density projects, or for critical facilities and infrastructure, the 500-year hazard window can be expanded to 1000 and 2500 years, respectively. Recognizing that fault offsets, regardless of age, and to some extent magnitude, can be mitigated by performance-based engineering design, it is also proposed that a revised A-P Act permit any mitigation alternative that results in a life-safety solution consistent with enacted building codes, recognizing that in many cases, avoidance may still be the only alternative. In addition to structures, modern fault zoning needs to reflect the significance of underground infrastructure within fault zones (e.g., water and sewer lines, electrical utilities), and require similar mitigation alternatives to protect communities from loss of their lifeline utility connections.

INTRODUCTION

In 1971, the M6.6 San Fernando earthquake produced 20 km of surface rupture along the San Fernando/Sierra Madre fault at the base of the San Gabriel Mountains. The 1.5 m reverse-slip rupture through a new housing development (figure 1) was the triggering event that led to the 1972 legislative adoption of a hazard-zoning law designed to prohibit future disasters due to surface-fault rupture through new residential subdivisions. Originally named the Alquist-Priolo Special Geological Studies Act (A-P Act), the name was changed in 1994 to the Earthquake Fault Zoning Act to better reflect its emphasis on the fault-rupture hazard (Bryant and Hart, 1994; Reitherman and Leeds, 1990).

From the Act's Preface: *"The purpose of the Alquist-Priolo Earthquake Fault Zoning Act is to **regulate development** near active faults so as to **mitigate the hazard** of surface fault rupture." [Emphasis added.]*

The A-P Act further defines its purpose: *"The purpose of this Act is to **prohibit the location** of most structures for human occupancy across the traces of active faults and to **thereby mitigate the hazard** of fault rupture." [Emphasis added.]* This change from the simple "mitigate" purpose noted above, is a critical distinction. While mitigate is open to options for engineering solutions, the only mitigation alternative now permitted by the law is avoidance; a binary solution, and one which is increasingly dated by the 40+ year progress of the geological, geotechnical, and structural engineering disciplines.

With its adoption in 1972, the A-P Act became the vehicle for an aggressive program of fault zoning by the California Geological Survey (CGS), and the mandating of fault avoidance in the planning of housing developments within those zones. Included with the A-P Act are a series of implementation guidelines and definitions prepared by the California State Mining and Geology Board (SMGB) (Bryant and Hart, 2007). This paper does not focus on the history of the A-P Act other than as a foundation from which to propose future modifications to the now four-decade old law and its current implementation.

The text of the A-P Act itself does not provide specifics of its technical implementation other than to spell out its enforcement responsibilities. The geological details of the program lie within the SMGB's definitions (Bryant and Hart, 2007), for example:

For the purposes of the A-P Act, an *active fault* is defined by the SMGB as one which has ***"had surface displacement within Holocene time (about the last 11,000 years)"***

"No structure for human occupancy, identified as a project under Section 2621.6 of the Act, shall be permitted to be placed across the trace of an active fault. Furthermore, as the area within fifty (50) feet of such active faults shall be presumed to be underlain by active branches of that fault unless proven otherwise by an appropriate geologic investigation ..., no such structures shall be permitted in this area."

Among the perhaps unintended impacts of the A-P Act due to this language are:

- All faults are considered equally hazardous, despite their varying rupture magnitudes or rupture recurrence intervals.
- Surface-rupture hazards are hugely over stated compared to any other hazard zoning in California municipal plans;
- Surface-rupture hazards are hugely over stated compared to the seismic shaking values used in design codes;
- Utilities and lifelines are preferentially placed within fault zones;
- Existing structures within A-P Zones often are not seismically retrofitted because they may be on a Holocene fault and the retrofit permit could trigger a fault investigation requirement. The unintended consequence here is that the fault under the structure may represent a significantly lower hazard than the regional ground-shaking hazard;
- Mitigation options other than simple avoidance are available today, which can, in some cases, provide better development options, but are not allowed by the A-P Act;
- Better mitigation alternatives will be developed in the future, and also will not be allowed unless the A-P Act is modified; and
- Fault rupture avoidance costs jobs and dollars, while alternative mitigation provides jobs and more development options.

IMPORTANT CONSIDERATIONS IN A NEW FAULT ZONING ACT

Preserve Professional Judgment

There needs to be room in a profession for professionals to utilize their experience and judgment in making decisions and recommendations. If everything is quantitatively prescribed by either code, standard, or law, then the decision for public safety has been shifted to the code, standard, and/or law writers, and geologic and geotechnical professionals are reduced to technicians merely taking measurements and samples. Interpretation, which is critical to the geologic site-characterization process, will have been eliminated. Professional judgment rests within the words "interpret", "about", "approximately", and "estimate"; not within 11,000.00 years, 4.00 inches, 50.00 feet, etc. The earth is more complicated than such precision implies, and to force the profession into using such precision is inappropriate, unprofessional, and may compromise both public safety and the public purse.

Soften Thresholds

When something numerical is placed into law, or even code, it is almost impossible to change later, despite evolving knowledge, materials, techniques, and acceptance. Take the "about 11,000 years" aspect of the current A-P Act. When that A-P Act was crafted, an "active fault" was defined as a fault that has Holocene rupture. An attempt was then made to help users by trying to define what that meant ("about the last 11,000 years"). Wright (1983, from the Preface) defined the Holocene as *"... that portion of the Quaternary period of geologic time that follows the last major phase of continental glaciation; it extends from about 10,000 or 12,000 years ago up to the present."* The "about" word in the A-P Act could thus easily be identified as ±1000 years. But in typical fashion, the geologic profession has defined the Holocene as starting 10,000 years ago (Palmer, 1983), and most recently 11,700 years ago (Walker and others, 2009). Absent geological judgment; however, that matters little to the rigid applier of numerical criteria; 11,700 = 11,700, not 11,500. Not even 12,800 ± 2000, which I have seen rejected by a reviewer as *"not old enough to permit the project."* The age of the last rupture must be 11,700.00, or less. In such rigid definitions, we are challenging a key geological issue; it is generally not possible to measure or date anything more accurately than 5-10% in perfect conditions, and maybe 20% in non-ideal stratigraphy.

Measuring discrete coseismic displacements at a project-specific site also poses significant challenges: (1) stratigraphic and pedogenic thicknesses are variable, (2) coseismic slip along a fault can vary by a factor of 2 or more in any earthquake, (3) kinematics of slip can vary depending on fault sense, strike, and geology, and (4) the techniques for mitigation are constantly in a state of flux as new analytical techniques, testing, instrumentation, materials, and ideas become available. Per our professional licenses, engineering mitigation and its permissible thresholds are not within the geologist's purview. Our responsibility is site characterization, meaning an appropriately detailed investigation that will provide a quantitative estimation of future coseismic displacements. This displacement estimation will be unlikely to be more precise than ± 25% without a near-perfect convergence of stratigraphy and structure, with hundreds of survey points defining them.

Balance Risks

The California A-P Act's definition of an active fault as having Holocene (now 11,700 yr B.P.) surface rupture is inconsistent with any other hazard's acceptable risk. Probabilistic thresholds of 1 in 10,000 are applied to the proposed Yucca Mountain nuclear waste repository, nuclear power plants, and some dams. Applying it for relatively low density, low rise, wood framed, residential structures, is so far outside of the normal risk acceptance of all other hazards, that we look foolish to much of the engineering profession, and incomprehensible to our clients. Why should we legally require avoidance for 1 in 11,700 year surface rupture (regardless of the magnitude of that rupture, the timing since the last event, or the recurrence between events), when the structure is only designed to resist 1 in 500 year earthquake shaking levels, or is sited within a 1 in 100 year flood plain? How can this not seem absurd? And furthermore, the definition and assumption (or avoidance) of risk is not our profession's to define. The engineering geologist's job is quantitative geologic site characterization, and risk is the purview of the owner and society, basing their decisions on our data and its interpretation.

Allow Multiple Mitigation Alternatives

The A-P Act mandate that fault avoidance is the only permitted mitigation alternative should be abandoned in favor of alternative, and perhaps complimentary, mitigation strategies. Mitigation alternatives are provided for seismic shaking, liquefaction, subsidence, landslides, flooding, and fires. Why is fault rupture so feared that avoidance is the only solution? Acceptable risk for other hazards hinges on mitigation; to have a law that prohibits mitigation for fault rupture, indicates that geologists feel we not capable of understanding faults well enough to mitigate rupture. While this might have been true in the 1970s, this is very definitely no longer the case. There is an extensive body of knowledge, research, and available techniques to permit a geologist to understand the pattern of surface rupture from past earthquakes, to appreciate the kinematic and geologic factors that control that rupture pattern, to quantitatively understand the past rupture behavior of a fault, and to use all of that knowledge to extrapolate forward and develop reasonably constrained and supported parameters for future rupture mitigation. But, the actual mitigation is not our responsibility. Our responsibility is accurate and quantitative site (and fault) characterization so that the engineers can develop and explore alternative mitigation approaches, and the owner can make a decision regarding the best mitigation alternative. It may be that the best (or only) mitigation alternative is still avoidance. But, it is not within our profession's knowledge base or professional license to make that determination. Geologists are not involved in the financial aspects of a project, we do not know what is economically feasible, and we may not know what is technically feasible. The geologist makes the determination of past (and therefore estimated future) displacements, then it is the responsibility of the owner, engineer, and society to determine the proper level of risk acceptance and best mitigation measure.

Upgrade the Profession

Until we recognize that having a Professional Geologist (PG) or Engineering (EG) license does not mean we know everything, nor does it mean that we need not continue to learn anything new, we are stuck in a perpetual "do" loop. As in "I can do anything." As a geotechnical professional, you are only licensed to do what you are competent to do, and being the professional that you are, you should be able to recognize what you do know, and what you do not know. Experience with detailed fault characterizations, as required for a mitigation option other than avoidance, lie within the competence of only a few dozen geologists. Nevertheless, the science of paleoseismology is not without its maturity. There are at least a dozen professors across the U.S. who are actively graduating students with an emphasis in neotectonics or paleoseismology. Most of these students go into industry where their academic knowledge is allowed to whither because all they need to do is make a binary determination whether the last surface displacement on a fault is older or younger than Holocene. This does not require extensive training or experience. There are many geologists in industry, many still too young to have a PG, who do have the skills and knowledge to take these investigations to new and better levels as would be required for mitigation. But, they need to get their ideas through the untrained, but stubbornly "knowledgeable," PG to whom they report. If fault-rupture mitigation is to be allowed as an option, then this current group of appropriately trained individuals will be the leaders in this new effort. Furthermore, it will open up new employment opportunities for the future graduates of paleoseismology programs.

Arguments are made that fault-rupture displacements and future rupture forecasts cannot be relied upon because of lack of consistency in current paleoseismic investigations. These are temporal issues, and as hundreds of new and detailed paleoseismic studies are conducted over the coming years in response to the mitigation options available for development projects, we will further improve our understanding of earthquake recurrence. If paleoseismology cannot currently be used to reliably predict future fault hazards, then let future researchers improve it so that it can be a viable tool. There was a time, decades ago, when landslide mitigation was also in its infancy, but today geological characterization and geotechnical mitigation are such common practices, at least in California, that they are now unremarked upon. Fault-rupture-hazard characterization might today be difficult, but tomorrow always brings new scientific and application breakthroughs.

Upgrade Reviewers

If we are to permit mitigation, then by default, a significant improvement in the technical competency of the practitioners in quantitative fault characterization is necessary. It is impossible to simply wish this to happen, it requires enforcement, and unless there are other ideas out there, the current enforcement arm of the profession lies with those working in the review sector (both public and some private). Simply digging hundreds (thousands) of meters of trench does not ensure a competent and quantitatively defensible job. Indeed many times less is better, but only if in the right place. A lot of those mega-trenches actually remove the data necessary for slip-per-event measurements. It will be vital to the success of fault-rupture mitigation to find some mechanism within which the reviewing community contains sufficient technical knowledge to allow it to differentiate quantity from quality, to be aware that their professional judgment is also in play, and that nothing is ever known 100% of the time. This has not been my experience even now, and if we are going to make interpretations more complex than *"is it exactly greater than 11,700 years old?"*, then there is a long way to go before this can be expected. It is like having a 55 mph speed limit on a straight road in Nevada and no law enforcement; it is not going to happen.

The Geological Survey's Role

Even in light of the comments above regarding reviewers, I am strongly not in favor of a reviewer role for the state geological survey. The CGS's role should be to continue to review the academic and industry findings for application to real-time A-P Act map revisions. The CGS should not be the reviewer of choice for cities or counties to turn to for assistance, and they most definitely should not be the "consultant" of choice for public agencies or private industry. I am a strong private sector advocate, not just because I believe in the capitalistic system, but because I think that the proper role of government is regulation, not application, and review is an application. Perhaps the best interim solution would be to empanel local review boards for fault-rupture-mitigation projects.

Professional Licensure

There seems to be considerable discussion (and belief) that an Engineering Geologist license should be required for fault investigation projects because the results of these studies lead directly into engineering. While this is only an issue in those few states that have an engineering geology license program, it is also a distracting argument. Most university professors are able to qualify for a PG license, but are unable to qualify for an EG license because of their lack of appropriate experience

working under an EG. It is incorrect to think that such a professor is (by law) not qualified to perform fault investigations to quantify rupture kinematics. What I find more disturbing is the apparent arrogance of (some) EG's that by having such a license they are thereby qualified to perform fault studies, though there is no basis from which to define their actual competency for conducting such studies. I am not in favor of yet another license within the geological profession. What I am in favor of is the development of more action to actually regulate incompetence, and thereby make us all more willing to seek technical assistance when we know that we do not know enough to do something correctly ourselves. Professional ethics cannot be licensed, but it is much more important than a license.

Engineering and Planning

I have noted above that with regard to the A-P Act, geologists take a lot of positions that do not seem to be ours to take. We use the word "Prohibit" a lot. Are we really able to rewrite the A-P Act and believe that prohibiting utilities within fault zones will not bring down the thunder from nearly everyone farther up the development chain? When you consider that the life expectancy of a sewer line is <10% of the recurrence interval of most faults, how and why do you expect to be taken seriously using "prohibit." An earthquake is simply another of the design cycles for that pipeline. We really need to communicate the risks better where there is a clearly dangerous situation, but ultimately, they are not our risks to assume, and I question our role in prohibiting anything.

Viability of Slip-Per-Event Measurements

It generally requires a unique set of geological conditions to allow any quantification of slip-per-event at a specific location along a fault. Most paleoseismic research sites focus on determining slip-rate and recurrence-interval data. Along any given fault there are typically only a handful of sites that will reliably yield these data, and the degree of variability from site to site is sometimes nearly 50%. To expect that most random development sites will yield both sediments and structures adequate to even estimate a slip-per-event (and slip kinematics) value, let alone actually permit a direct measurement, is to simply be unaware of the science involved in doing such investigations. Be aware also, that if we are going to do more than prohibit development, then the investigations will become several orders of magnitude more complex. We will have to be able to rely upon work done elsewhere along the fault, we will have to be able to rely upon empirical measurements and observations from other faults and earthquakes, and the number of geologists who currently can do this work well is very small. But, just because something is difficult, should not prohibit those able to, or lucky enough to, do it. Just be aware that this will be a very rare event indeed, and will be fraught with considerable professional judgment and risk acceptance. But, at the same time, this will move our geologic profession much farther along than it is today, and it will gain us greater respect within the engineering community, which is moving rapidly along a probabilistic and performance-based design philosophy. In addition, the professional ability to capture and incorporate uncertainly in design decisions is so rapidly evolving in the engineering community that the geologist's *"we cannot know this perfectly"* is becoming an old story.

GENERAL OBSERVATIONS PERTINENT TO THE A-P ACT

1. The current A-P Maps are static. In a digital age, it should be possible to require regular updates to zones and zone widths as new data becomes available. Why does a zone need to be 1500 feet wide through a subdivision when all of the Holocene faults were accurately mapped before the subdivision was approved and the hazard thereby mitigated? What about Holocene faults that are outside of A-P Zones? What about the many faults that are demonstrated to be pre-Holocene? Hazard maps should be dynamic, and evolve as the hazard is better defined, just like all geologic understanding evolves with new data.

2. The SMGB's original Technical Advisory Board's proposed change from zero to four inches of displacement achieves too little. Depending on the fault kinematics, the geotechnical and structural characteristics of the project, the creativity of the design team, the competence of the reviewing team, and on future technologies and professional development, the only thing that should be mentioned in the A-P Act is mitigation per building code provisions. If the fault displacement cannot be mitigated to acceptable safety levels within code, then avoidance is the solution. But let geologists, engineers, and owners at least try to be creative first.

3. Fault-rupture risk needs to be balanced against other societally accepted risks. It should be appropriate to the performance from ground shaking applied within the structural codes. It should be appropriate to the floodplain hazard upon

which it is sited. It should be appropriate to the geotechnical mitigation designs for the mitigation of other seismic issues.

4. The "one size fits all" methodology of the current zoning is inappropriate and inconsistent to other engineering solutions. Engineering safety considerations are different for a single-family home, for a shopping mall, for a high rise building, or for a hospital. I propose a hazard window of 500 years from average recurrence for residential development, 1000 years for high occupancy structures, and 2500 years for critical structures (see examples below).

5. I propose that if a secondary fault has not experienced renewed displacement in 2-3 main trace events, then it should no longer be considered a hazardous fault.

6. Professional judgment must be preserved in the process somehow. Perhaps an appeals board for contentious project proposals. Perhaps just a highly competent review board?

7. There needs to be a digitally accessible clearinghouse for all paleoseismic investigations so that the State and all other professionals can benefit from these investigations. The current archival system does not adequately facilitate real-time accessibility and utility of the investigation data. Within 10 years, we will have solidly constrained recurrence intervals on all of these faults. We will have constrained kinematics for the last couple of earthquake events. We will have actually applied a lot of the fault-rupture documentation out there because for the first time it will be important to know how faults rupture through bends and steps We will begin to really understand main trace rupture and secondary dispersed ground deformation effects. Currently, all of this is trashed. But just think how nice it would be to have such a database for statewide seismic hazard and risk modeling.

PROPOSAL FOR A-P ACT REVISION

- Moderate the prohibition of structures across faults as the only permitted mitigation measure by adding *"unless appropriate mitigation measures are implemented to comply with the intent of the Act."*

- The intent being to mitigate the fault-rupture hazard to a satisfactory degree per building codes, which could include mitigation by avoidance if the cost (investigation, design, or construction) is too high or the displacements are too large.

This will bring the geologic risk of fault rupture into compliance with socially and technically accepted risk management for other geologic and natural hazards. Additionally, revise the definition of an "active fault" to better conform to the level of hazard by recognizing that not all projects pose equal risk, so scale the hazard triggers by vulnerability and risk.

- Add … *"a fault shall be considered hazardous and subject to mitigation for residential projects if it is within 500 years of its average recurrence interval."* This conforms to the 10% probability of exceedence in 50 years for ground shaking that generally applies to design of single-family homes.

- And … *"a fault shall be considered hazardous and subject to mitigation for high density occupancy projects if it is within 1000 years of its average recurrence."* This conforms to the 10% probability of exceedence in 100 years for ground shaking that is generally applied to life safety of larger structures.

- And … *"a fault shall be considered hazardous and subject to mitigation for critical facilities projects if it is within 2500 years of its average recurrence."* This is conformable to the 2% probability of exceedence for ground shaking that forms the basis of most codes for critical infrastructure.

- And … *"a secondary fault shall be considered non-hazardous if it can be shown to have not ruptured during two or three (or more for critical structures) main trace events.*

These revisions will allow geologists to do their jobs to adequately characterize a fault's paleoseismic history and displacement kinematics.

Examples

1. Santa Monica fault: Most recent event ~3 ka. Recurrence interval 10+ ka. Today – active fault per A-P Act, subject to avoidance for all projects. Proposal – not a hazardous fault for any project.

2. Hollywood fault: Most recent event ~8.5 ka. Recurrence interval ~10 ka. Today – active fault per A-P Act, subject to avoidance for all projects. Proposal – not a hazardous fault for residential projects, but a critical facility would be required to investigate the hazard, and using professional judgment, a large high-occupancy facility could be required to investigate the fault-hazard exposure.

3. Whittier fault: Most recent event ~1.6-2.0 ka. Recurrence interval ~2 ka. Today – active fault for any project under A-P Act, subject to avoidance for all projects. Proposal – hazardous fault and subject to mitigation for all projects.

4. Northern Newport-Inglewood fault: Most recent event Holocene. Recurrence interval unknown. Today – active fault per A-P Act, subject to avoidance for all projects. Proposal – unknown most recent event and recurrence would require additional data collection to define fault unless setbacks are imposed.

5. San Jacinto fault (SJF) and secondary traces: Main SJF recurrence interval 250 years. Most recent event ~250 years ago. Hazardous fault. Secondary traces, last ruptured 5 ka, 20 SJF events ago during migration of extensional step-over. Not a hazardous fault for any project.

SUMMARY

The intent of this paper is to present a path forward to modernize the California Alquist-Priolo Earthquake Fault Zoning Act, or to assist other states in writing their own fault-rupture-hazard policy, to better reflect the advances that have been made in earthquake geology, geotechnical engineering, structural engineering, and materials science in the 40+ years since the A-P Act was passed. The Act's original intent to mitigate the hazard of surface-fault rupture by requiring detailed geological investigations evolved into the simple prescriptive mitigation of avoidance of faults as the only approved mitigation alternative for buildings for human occupancy. In doing so, most residential subdivisions were designed with the faults aligned with the development's major roadway network, which often also contain the primary underground utility lifelines for a subdivision, an unsafe condition and unintended consequence of a fault-avoidance-only policy.

Allowing the new definition of a hazardous fault to better reflect other defined societal hazard criteria, and permitting alternative mitigation for those hazardous faults will lead to a more robust geological knowledge base for many faults, and an improved seismic-hazard database, across the state. Detailed geological investigations of fault kinematics will become the new standard of practice, and geotechnical and structural engineering will likewise see increased applicability. Making the fault-hazard-zoning maps more dynamic will eliminate wasted effort in those areas where the hazard has been fully constrained, and allow for new findings to be rapidly distributed to affected communities and practitioners. An open discourse about the unintended consequences of the current A-P Act's language and its interpretation should lead to an improved awareness of the true costs of strict fault-rupture avoidance. It is well past time to fix this Act.

Figure 1. *New home damaged by reverse-fault displacement through a residential subdivision during the 1971 San Fernando earthquake. This image became the "poster child" that led to the California legislative initiative to regulate future development within active fault zones. USGS Circular 690: http://pubs.usgs.gov/circ/1974/0690/report.pdf (USGS photo).*

REFERENCES

Bryant, W.A., and Hart, E.W., 2007, Fault-rupture hazard zones in California—Alquist-Priolo Earthquake Fault Zoning Act with index to earthquake fault zones maps: California Geological Survey Special Publication 42, 42 p.

Palmer, A.R., 1983, The decade of North American geology, the 1983 geologic time scale: Geology, v. 11, p. 503-504.

Reitherman, R., and Leeds, D.J., 1990, A study of the effectiveness of the Alquist-Priolo Program: California Geological Survey Open-File Report 90-18, 131 p.

Walker, M. and eighteen others, 2009, Formal definition and dating of the GSSP (Global Stratotype Section and Point) for the base of the Holocene using the Greenland NGRIP ice core, and selected auxiliary records: Journal of Quaternary Science, v. 24, p. 3-17.

Wright, H.E., Jr., editor, 1983, Late Quaternary environments of the United States, volume 2, the Holocene: Minneapolis, Minnesota, University of Minnesota Press, 277 p.

The following is a PDF version of the author's PowerPoint presentation.

Modernizing the 1972 California Alquist-Priolo Fault Zoning Act for the Performance-Based Millennium

Eldon Gath

Earth Consultants International

SPECIAL PUBLICATION 42
Interim Revision 2007

FAULT-RUPTURE HAZARD ZONES IN CALIFORNIA

Alquist-Priolo Earthquake Fault Zoning Act with Index to Earthquake Fault Zones[1] Maps

[1] Name changed from Special Studies Zones January 1, 1994

DEPARTMENT OF CONSERVATION
California Geological Survey

CGS Special Publication - 42

PREFACE

The purpose of the Alquist-Priolo Earthquake Fault Zoning Act is to **regulate development** near active faults so as to **mitigate the hazard** of surface fault rupture.

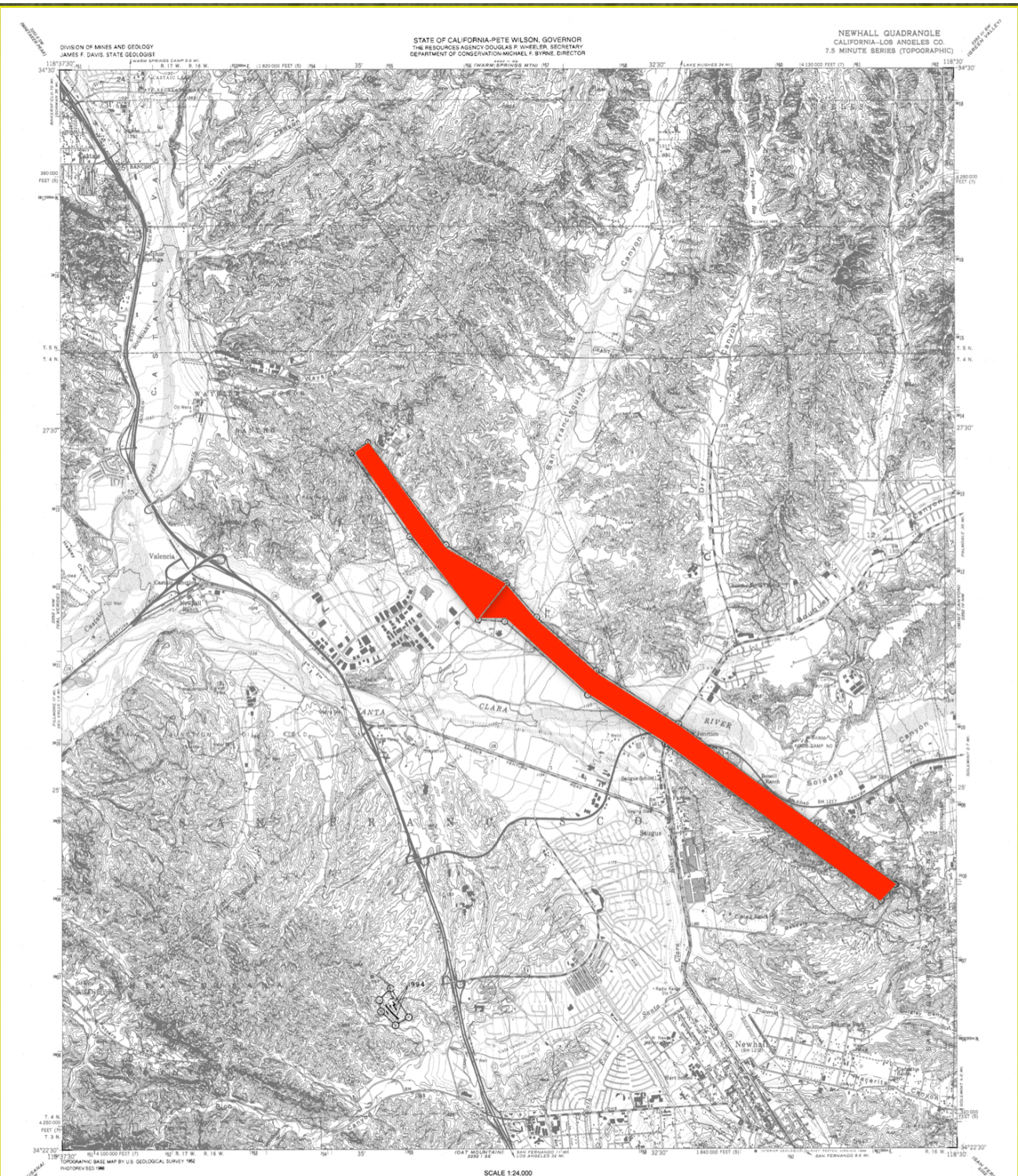
Alquist-Priolo Act

The purpose of this Act is to **prohibit the location** of most structures for human occupancy across the traces of active faults and to **thereby mitigate the hazard** of fault rupture (Section 2621.5).

Only mitigation measure permitted – Avoidance

Mixed messages

11 revisions to the Act – why not a 12th ?


STATE OF CALIFORNIA-PETE WILSON, GOVERNOR
THE RESOURCES AGENCY-DOUGLAS P. WHEELER, SECRETARY
DEPARTMENT OF CONSERVATION-MICHAEL F. BYRNE, DIRECTOR
DIVISION OF MINES AND GEOLOGY
JAMES F. DAVIS, STATE GEOLOGIST
NEWHALL QUADRANGLE
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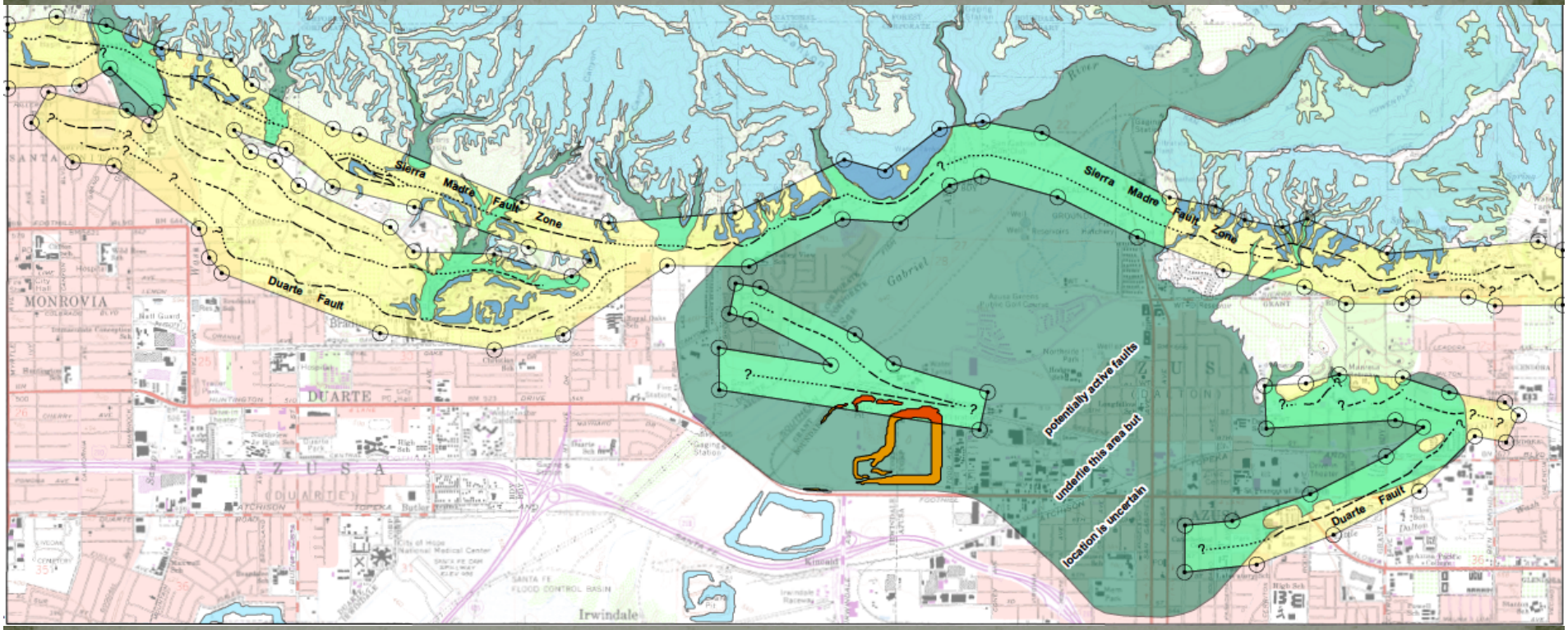
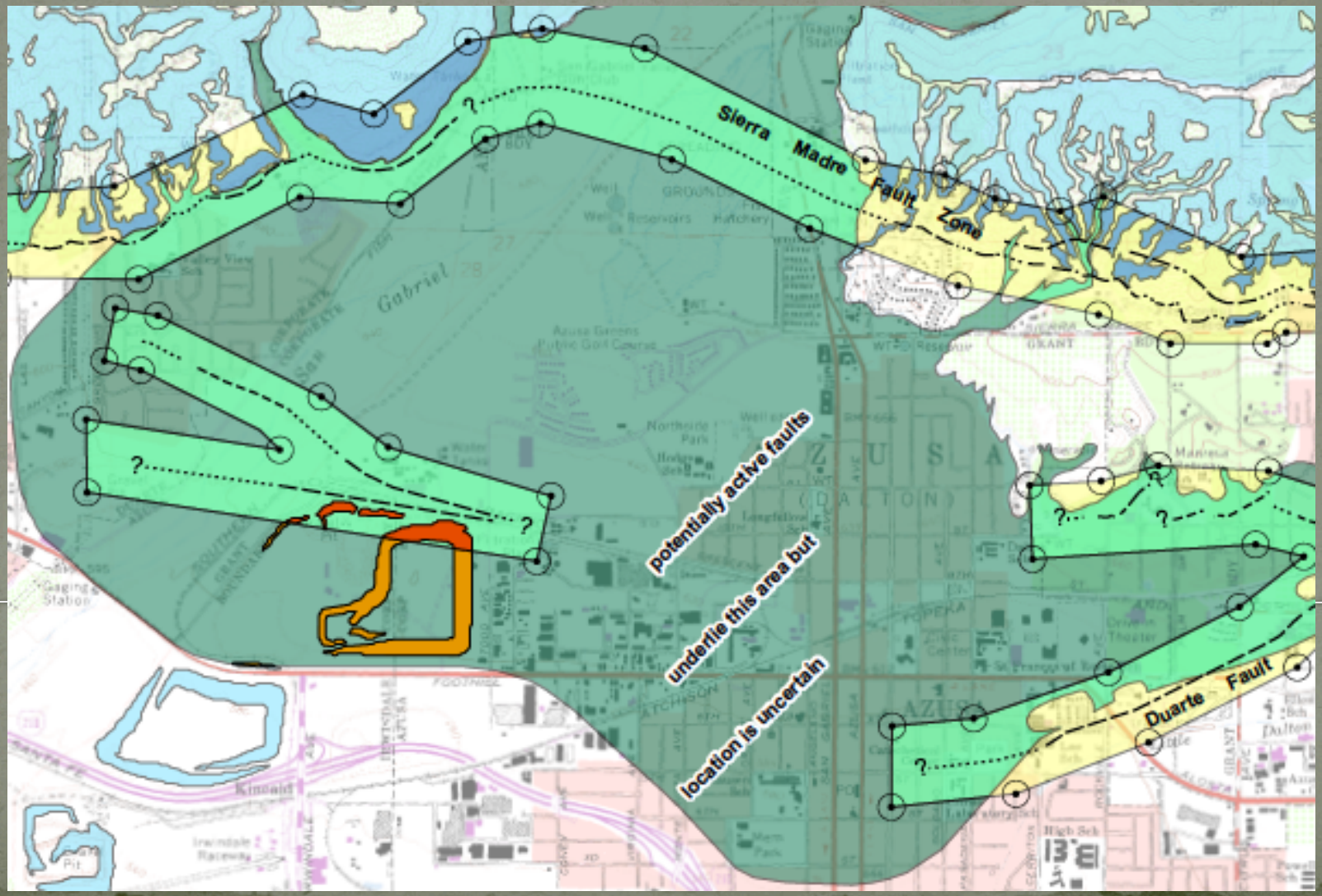
Santa Clara River
San Francisquito Canyon
Bouquet Canyon
Placerita Canyon
Sand Canyon
Solemint Junction
Bonelli Ranch
Mint Canyon
Oat Mountain
Radio Relay Sta
Elsmere Canyon
Del Valle
Pico Canyon
Castaic Junction
Castaic Creek
Castaic Lake
Castaic Lago

Some Zones Affect An Entire Community



Most of these faults are inferred from groundwater levels

"Potentially active faults underlie this area but location is uncertain"



Active Fault – how defined?

For the purposes of this Act, an *active fault* is defined by the State Mining and Geology Board as one which has **"had surface displacement within Holocene time (about the last 11,000 years)"** (see Appendix B, Section 3601). This definition does not, of course, mean that faults lacking evidence for surface displacement within Holocene time are necessarily inactive. A fault may be presumed to be inactive based on satisfactory geologic evidence; however, the evidence necessary to prove inactivity sometimes is difficult to obtain and locally may not exist.

CGS Note 49

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.

1972 thinking. Still valid?
Is this only geologist-thinking?

CGS Note 49

Most surface faulting is confined to a relatively narrow zone a few feet to a few tens of feet wide, making avoidance (i.e., building setbacks) the most appropriate mitigation method. However, in some cases primary fault rupture or 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).

CGS Note 49

The scope of the investigation is dependent not only on the complexity and economics of a project, but also on the level of risk acceptable for the proposed structure or development. A more detailed investigation should be made for hospitals, high-rise buildings, and other critical or sensitive structures than for low-occupancy structures such as wood-frame dwellings that are comparatively safe.

This seems to be very inconsistently applied.

CGS Note 49
F. Consultant's Recommendations

1. Setback distances of proposed structures from hazardous faults. The setback distance generally will depend on the quality of data and type and complexity of fault(s) encountered at the site.

2. Additional measures (e.g., strengthened foundations, engineering design, flexible utility connections) to accommodate warping and distributive deformation associated with faulting (Lazarte and others, 1994).

3. Risk evaluation relative to the proposed development.

SMGB 3603. Specific Criteria

No structure for human occupancy, identified as a project under Section 2621.6 of the Act, shall be permitted to be placed across the trace of an active fault. Furthermore, as the area within fifty (50) feet of such active faults shall be presumed to be underlain by active branches of that fault unless proven otherwise by an appropriate geologic investigation ..., no such structures shall be permitted in this area.

Tolerable Levels of Ground Motion

- Conventional construction – 1 inch
- Post-tensioned residential slabs – 1.5 inch
- Liquefaction-induced settlement – 4 inches
- Liquefaction-induced lateral motion – 12 inches

- **Fault Rupture – 0 inches**

Does the structure care WHY the ground moved?

- Cannot always avoid active faults
- Not all "active" faults are hazardous – 11,000+ year risk is excessive
- Unintended consequences – utilities go in fault zones
- "Unless proven otherwise" is too stringent, hard to prove, hard to get approved
- Can design for landslide movements, mining subsidence, liquefaction, subsidence, why not fault displacement?
- Because of the 1972 Alquist-Priolo Act

Alquist-Priolo Earthquake Fault Zoning Act

1972-2015

Have we learned nothing in 43 years?

1971 San Fernando EQ

Poster Child of the Alquist-Priolo Act

No fatalities from surface fault rupture – so buildings are banned from faults

1971 San Fernando EQ

The Real Earthquake was Elsewhere

65 fatalities from structural failure – so we improved the building codes

1972 – 2015 : Lessons Learned

- 1977 – Kerry Sieh's Pallet Creek PhD
- Over 100 geologists with active fault investigation experience since then
- Dozens of surface-rupturing earthquakes researched around the world (LFE Program)
- Geotechnical engineering programs – huge advances in laboratory and analytical capacity
- Structural engineering now done using computers with real stresses and strains
- Materials sciences – space age advances, NEES

Is this really where we are at now?

The Mega-Trench Future?

4 inches in 14,000 years?

2-inches in 500,000 years?

Abandoned Projects ?

200-Year Flood in California

"More Devastating Than Major Quake"

USGS Says

A massive California rain event -- one expected to occur once every 200 years -- would far surpass destruction caused by a "Big One" earthquake, causing more than $700 billion in damage and hobbling the state's economy for decades, federal scientists are warning.

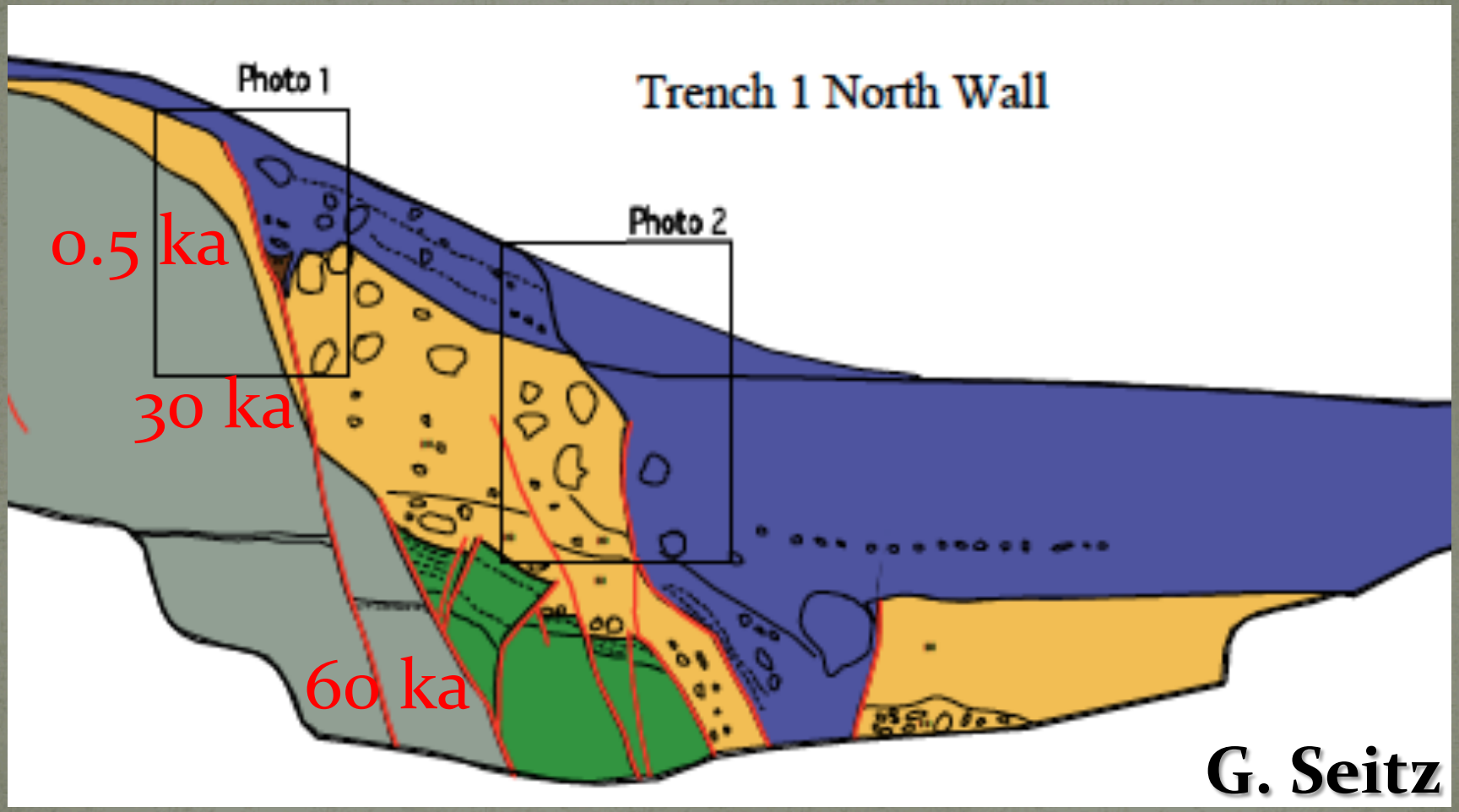
Buena Park - 1938

Multi-Hazard Management

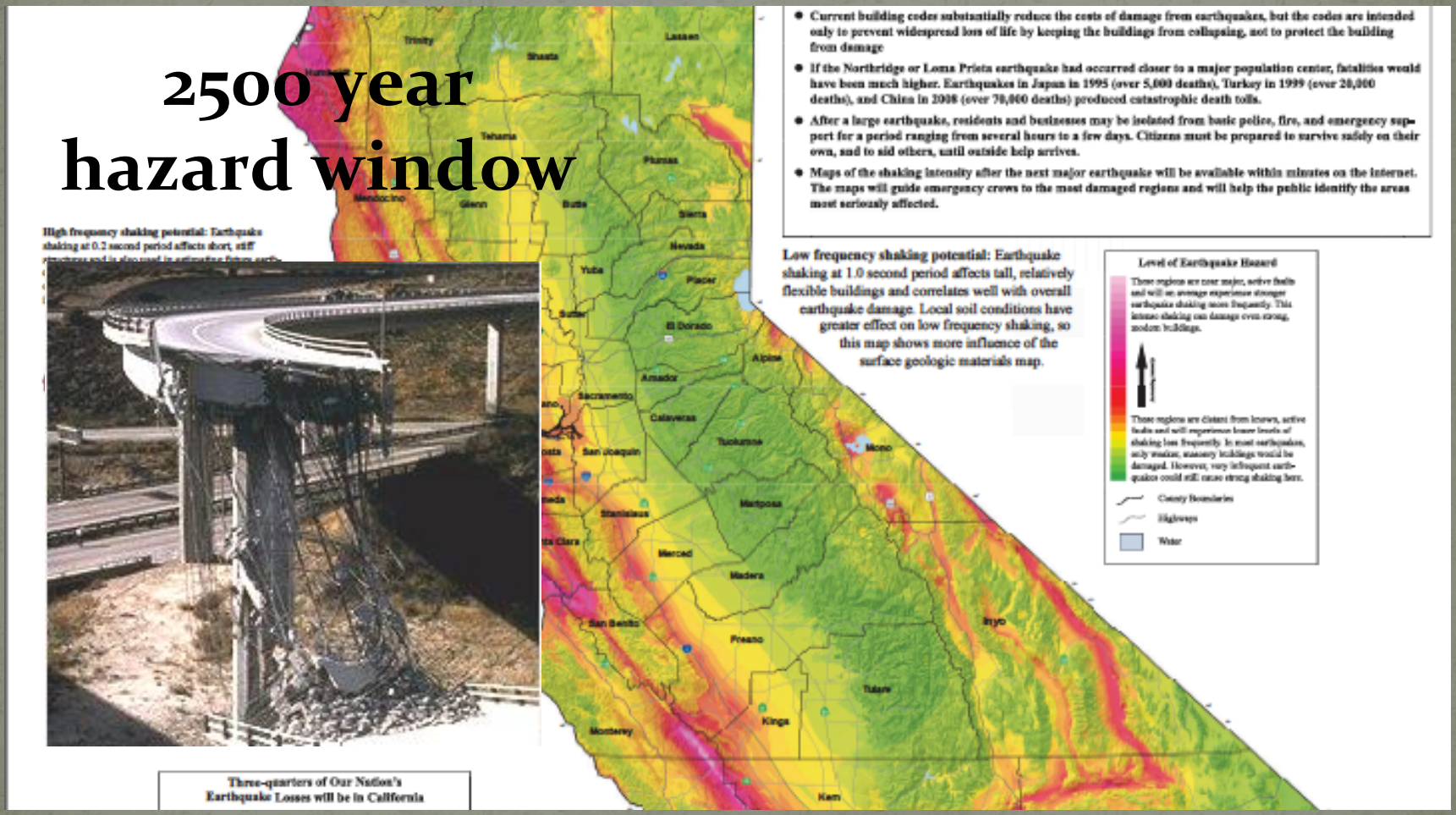
Risk Based

North Lake Tahoe

Planned for A-P Zoning



California's Seismic Hazard Map



Good enough?

How [in]consistent are we?

- Flood Hazard Zones – 100 years normal, 500 years critical facilities
- Seismic Design – 450 years for homes, 975 years for other buildings, 1500 years for critical bridges, 2500 years for hospitals.
- Slope stability – based on seismic input, 475 years
- Liquefaction mitigation – 475 years
- Fault rupture avoidance – 11,700 years

CALIFORNIA PUBLIC RESOURCES CODE

Division 2. Geology, Mines and Mining

CHAPTER 7.5 - EARTHQUAKE FAULT ZONING

2623. **CGS makes the maps, not policy**

- (a) the State Geologist shall delineate … appropriately wide earthquake fault zones to encompass all potentially and recently active traces of the San Andreas, Calaveras, Hayward, and San Jacinto Faults, …
- (b) and shall submit those maps to all affected cities, counties, and state agencies, not later than December 31, 1973, for review and comment.
- (c) The State Geologist shall continually review new geologic and seismic data and shall revise the earthquake fault zones or delineate additional earthquake fault zones when warranted by new information.

CALIFORNIA PUBLIC RESOURCES CODE
Division 2. Geology, Mines and Mining
CHAPTER 7.5 - EARTHQUAKE FAULT ZONING

2623.

- (a) The approval of a project by a city or county shall be in accordance with policies and criteria established by the State Mining and Geology Board and the findings of the State Geologist. In the development of those policies and criteria, the State Mining and Geology Board shall seek the comment and advice of affected cities, counties, and state agencies.

SMGB set all definitions, not the A-P Act

CALIFORNIA PUBLIC RESOURCES CODE
Division 2. Geology, Mines and Mining
CHAPTER 7.5 - EARTHQUAKE FAULT ZONING

2630.

- In carrying out the provisions of this chapter, the State Geologist and the Board shall be advised by the Seismic Safety Commission.

Best place to incorporate risk analysis?
Best place to integrate fault rupture into building codes?
Where are the engineers?

So what are the obvious issues?

- Surface rupture hazards are hugely over-stated compared to other hazard zoning
- Surface rupture hazards are hugely over-stated compared to seismic shaking in design codes
- Other mitigation options are possible today, providing engineering and geology jobs and better development options
- Better mitigation alternatives will be developed in the future
- Fault rupture avoidance costs significant jobs and dollars, alternative mitigation provides jobs

A-P Compliant Fault Investigations are Hugely Expensive

$500K - 6 trenches - no faults

$750K - 3 trenches - 20 borings
no faults in 200+ ka

$1.8M - 2 trenches – 1000’ long x 65’ deep
1 fault – 18” displacement – 200++ ka

$3M - 5 trenches – 30 borings – 12 CPTs
1 fault – > 200++ ka

Direct Revision of the A-P Act

- Moderate the prohibition of structures across faults as the only permitted mitigation measure.
- Add **... unless appropriate mitigation measures are implemented to comply with the INTENT of the Act.**
- **The INTENT being to mitigate the fault rupture hazard to a satisfactory degree per the building codes**
- Bring the geologic risk of fault rupture into compliance with socially and technically accepted risk management for other geologic and natural hazards
- Utilize the strength of the BPELSG Board and the BIA to gain legislative approval
- Improve understanding and training within the geologic and engineering professions

Revision of the A-P Act's Policies

- Revise the definition of an "active fault" to better conform to the level of hazard
- Add **… a fault shall be considered hazardous and subject to mitigation if it lies within 500 years of its average recurrence interval.**
- Allow geologists to do their jobs to adequately characterize a fault's kinematics and paleoseismology
- Structural and Geotechnical Engineering mitigation solutions need to be permitted if they demonstrate adequate safety factors – exactly the same as all other engineering solutions.

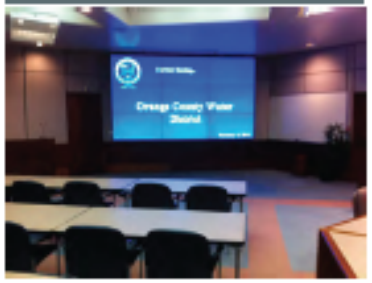
Recognize that not all projects pose equal risk

Scale the hazard triggers by the vulnerability and risk

- Within 500 years of average recurrence for residential
- Within 1000 years of average recurrence for high density occupancy
- Within 1500 years of average recurrence for critical facilities

The Path Forward – requires education

Workshop Location



Orange County Water District

18700 Ward Street
Fountain Valley, CA 92708

www.ocwd.com

Friday May 10, 2013
8:00 – 9:00 Reg. & Social
9:00 – 12:30 Presentations
1:00 – 2:30 Presentations
2:45 – 4: 30 Discussions

This Workshop focuses on the latest geotechnical and structural engineering concepts to mitigate surface fault rupture. The interdisciplinary forum allows the participants to go beyond the current regulatory restriction of total fault avoidance regardless of site-specific procedures now available to mitigate risk to life and property.

Registration Information

Name

Affiliation

Address

City, State, Zip

Email

- Mail check for $85, payable to AEG, to: Eldon Gath, c/o Earth Consultants Int., 1642 E. 4th St., Santa Ana, CA 92701
- Space-available registrations at the door will be $100. These cannot be assured and lunch may not be provided.
- The event is limited to 100 people.
- A sandwich lunch and drinks will be provided.

Contact Eldon Gath for further information: 714-412-2653 or gath@earthconsultants.com

Surface Fault Rupture

New Mitigation Concepts and Political Challenges

AEG • ASCE • EERI

A Knowledge and Technology Transfer Workshop

May 10, 2013

The Path Forward – requires partners

- Previous efforts to modify the A-P Act to permit other mitigation measures bogged down
- Geologists are now part of the Engineering Board (BPELSG) and together we have a voice
- The Building Industry needs to be brought on board as mitigation advocates along with us
- WSSPC and other B&R States can support
- We present it as a win-win-win. Good jobs, better projects, safer citizens

Alquist-Priolo Earthquake Fault Zoning Act

2015 – and onward to the future

We have learned a lot in 43 years, and it is time to put it into practice.