Surface Faulting and Deformation
Assessment & Mitigation

Summary of a Shlemon Specialty Conference
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for the PEER Workshop on
Surface Fault Displacement Hazard

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California Geological Survey
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Photo by Bill Bryant
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Request for changes in regulations and practice to allow mitigation by design ...

Be careful what you ask for ...

Photo by Earl Hart
critical questions:

1. Where should fault rupture and deformation be anticipated?

2. How much slip and in what sense, should be anticipated?

3. How do we anticipate the hazard based on incomplete data?

4. What can be done about the hazard?
critical questions:

1. Where should fault rupture and deformation be anticipated?

… not just the simple location, but the geometry, style, distribution, and complexity of faulting
Where should fault rupture and deformation be anticipated?

-- strike-slip faulting

Superstition Hills Earthquake - 1987

Photo by Jerry Treiman
1) Where should fault rupture and deformation be anticipated?

-- normal faulting

Hebgen Lake Earthquake - 1959

Photo #5 from J.B. Hadley Collection, U.S. Geological Survey
Courtesy of U.S. Geological Survey
1) Where should fault rupture and deformation be anticipated?

-- reverse and thrust faulting

Chi Chi Earthquake -- 1999

San Fernando -- 1971
Single Fault Trace
Complex Faulting
In reality, rupture commonly is more complex.
Strike Slip – integration of en echelon faults

From Tchalenko, 1970
Fault patterns at different scales

Figure 11. Comparison of residual structure in shear zones of different magnitudes. (A) Dasht-e Bayaz earthquake fault (after Tchalenko and Ambraseys, 1970, Fig. 5). (B) Riedel experiment. (C) entire shear box sample (see also Fig. 8A). (D) detail of shear box sample. Total displacements are given in the text. Dotted lines indicate less prominent shears. The structures plotted in the form of rose diagrams show Riedel, P shear and principal displacement shear directions.
Transtension

photo by Jerry Treiman
1) Where should fault rupture and deformation be anticipated?

Normal faults

Photo by Karl Steinbrugge

Courtesy of the National Information Service for Earthquake Engineering, University of California, Berkeley
Chi Chi Earthquake 1999 demonstrates complexity orthogonal to fault.
Definition of Terms

– **Primary fault** - the trace where the majority of co-seismic displacement occurs

– **Secondary or Branch fault** - a subordinate trace that connect to the primary fault in either map view or at depth, where minor co-seismic rupture occurs

– Bending moment fault

– Sympathetic fault rupture

– Shaking induced displacements
Definition of Terms

- Primary Fault
- Secondary Faults
- Branch Fault
- Zone of Energy Release
- Shaking Induced Displacement
- Sympathetic Rupture
- Modified from drawing by Bill Frazier, DWR
1) Fault rupture to fault deformation – what is a surface fault?
Since much of our site information comes from trenches we may not see the full expression of prior rupture at the site.
… the next rupture may be part of the evolution of the fault zone.

photo by Jerry Treiman
2. How much slip, and in what sense, should be anticipated?

photo by Jerry Treiman
2. How much slip and in what sense, should be anticipated?

We looked at two dimensions of variability in slip:

• temporal variation – from one earthquake to the next

• spatial variation – along a fault zone in any one event

photo by Jerry Treiman
Comparison of total slip for the 1966 and 2004 Parkfield earthquakes

Temporal slip variation

from Lienkaemper and others, 2006
Overlap of rupture events on the southern San Andreas Fault
Parkfield to Salt Creek

-- one possible history --

Temporal slip variation

from Weldon, 2004
Slip will vary from one quake to the next based on:

- variability of short-term slip rate
- difference in interval/accumulated strain since last event (strain rate x time since last event)
- % of strain release in an event
- rupture of shorter/longer segment
- where you are in a rupture segment
- shift of slip distribution between strands

**Temporal slip variation**
Event 35
Nov 12 1999 Duzce, Turkey

Spatial slip variation
from Wesnousky, 2008
Characteristics of Surface Rupture Depend on:

- fault type
- inclination of fault plane
- amount of fault displacement
- fault definition
- geometry of overlying material
- nature of overlying material
3) How do we anticipate the hazard based on incomplete data?

**Summary of limitations:**

- incomplete knowledge of fault pattern
- incomplete knowledge of past behavior and slip rate
- non-repeatability of displacement amount
- most of our data comes from trenches
Fault Activity

• Is a fault active?

• How do we define “active”?

• Somewhat arbitrary – there can be no absolute assurance that a fault is “dead”.

• Commonly based on time frame (e.g. Holocene)

• Better approach may be based on slip-rate and fault history, where you have the data.
Understanding the style of faulting

Coronado Fault

Proposed tunnel

Coronado bridge/tunnel – San Diego, CA
Coronado bridge/tunnel – San Diego, CA
4) What can be done about the hazard?

Basically the only way to avoid damage from surface rupture and associated deformation is through application of a buffer around those uncertainties.

- **Spatial buffer** -- physical setback -- look beyond your trench data to the big picture of the mechanism/style of faulting in order to avoid faults and associated significant deformation.

- **Design buffer** -- develop realistic estimates of sense and magnitude of displacement with generous margins of error. Requires good science, not guesswork.
Building Locations
• AEG conference focused on engineering projects that may have a choice of avoidance.

• Lifelines do not have that luxury (although you may have some choice in where to cross faults).

• Proper characterization is key.