Shear Movement in Near-Field Rock Due to Large Earthquakes

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Presentation Outline

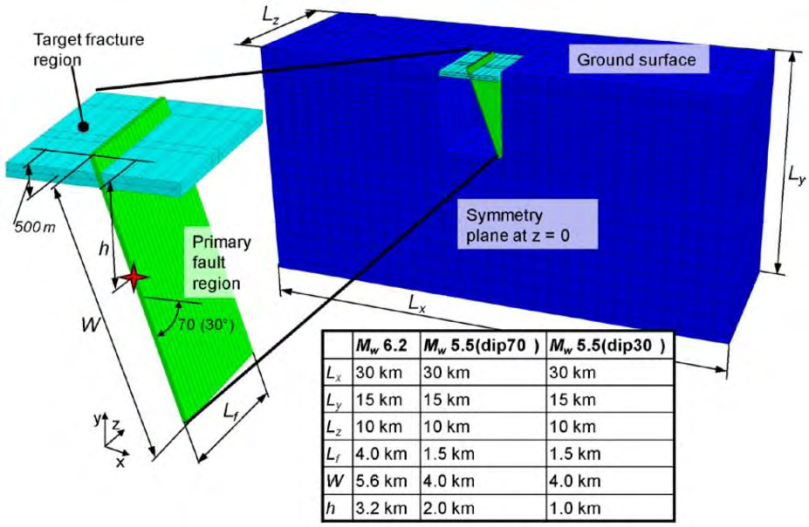
- Safety Issue
- SKB Geomechanical Modeling
  - Initial Static Equilibrium
  - Dynamic Phase
- SKB's Calculated Fracture Behavior
  - Fracture Stability
  - Slip Magnitudes
- SKB's Proposed Respect Distances from Known Faults
- Evaluation of SKB Analysis

Safety Issue:
Shear Movement in Near-Field Due to Large Earthquakes

- Induced slip on fractures that intersect deposition holes
- Impairment of buffer-canister system integrity
  - If slip magnitude and velocity are large enough
  - Damage from plastic deformation of canister
- SKB approach
  - Consider fracture slip of 0.05 m or greater as indicating canister damage
  - Avoid deposition hole locations close to fractures that could slip 0.05 m or more during a potential earthquake
  - Assess probability of canister damage due to fracture slip if fracture avoidance cannot be implemented
- SKB performed analysis to categorize fractures based on slipping 0.05 m or more during a potential earthquake
- SwRI reviewed SKB's quantification of fracture slip in the near-field rock due to large earthquakes

SKB Geomechanical Model

- Model incorporates
  - Earthquake-generating fault (primary fault)
  - Fractured rock representing a generic host rock (target fracture region)
- Target fracture region large enough to contain several circular planes of 150 m radius representing fractures
- Model large enough to permit appropriate boundary conditions for dynamic faulting analysis
- Considered a steeply dipping fault and shallowly dipping fault
- Varied fracture dips, dip directions, and distance from fault



	M_w 6.2	M_w 5.5(dip70)	M_w 5.5(dip30)
L_x	30 km	30 km	30 km
L_y	15 km	15 km	15 km
L_z	10 km	10 km	10 km
L_f	4.0 km	1.5 km	1.5 km
W	5.6 km	4.0 km	4.0 km
h	3.2 km	2.0 km	1.0 km

Fälth et al. (2010), SKB TR-08-11, Figure 4-1, p. 37.

Evaluation of SKB Analysis (1 of 4)

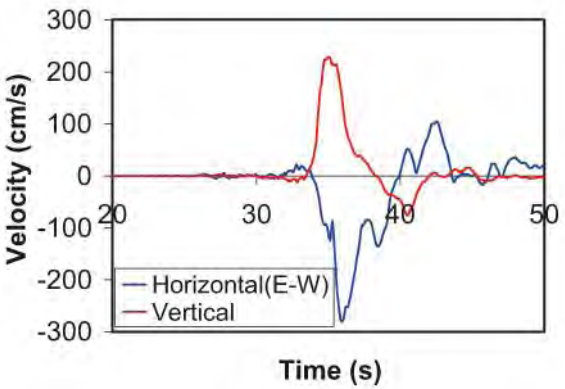
- SKB analysis can support an assessment of induced shear deformation due to earthquakes
  - Analysis was performed using well-established geomechanics modeling code (3DEC)
  - Meaningful range of parameter values was used
    - Fault and target fracture geometry
    - Mechanical properties
    - In situ stress magnitude and orientation
  - Procedures for slip rupture initiation and propagation on fault are well established

- However, reviewers have 4 unresolved concerns regarding SKB calculated fracture slip magnitudes

Evaluation of SKB Analysis (2 of 4)

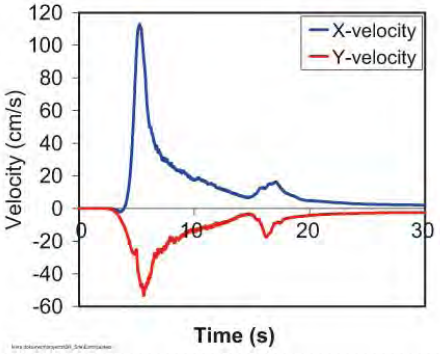
- Are ground motions from the simulated fault slip representative of ground motions from a representative earthquake that could occur at the site?
  - What really matters is ground motion
  - Source fault characteristics are important only to the extent that they affect the ground motion magnitude and frequency
  - Does ground motion from SKB simulated fault slip compare well with ground motion from representative earthquake?
  - Need systematic and quantitative comparison

1999 Chi-Chi Earthquake



Fälth et al. (2010), SKB TR-08-11, Figure 6-11, p. 106.

SKB Model

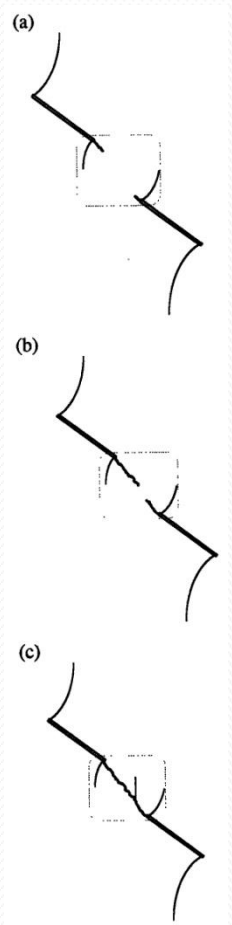


Fälth et al. (2010), SKB TR-08-11, Figure 6-10, p. 106.

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Evaluation of SKB Analysis (3 of 4)

- How is potential coalescence of fractures accounted for in the slip magnitude versus fracture size relationship?
  - Slip magnitude increases linearly with fracture size
  - Fracture coalescence would result in increased fracture size
  - Persistent unstable stress condition after simulated event indicates rock bridge around fracture could fail during the event
  - Rock bridge failure could permit fracture coalescence



Shen et al. (1995), J. Geophys. Res., Figure 6, p. 5980.

Evaluation of SKB Analysis (4 of 4)

- How did stress states in the target fracture region evolve during the simulated seismic event?
  - Slip on existing fractures depends on the evolving stress state due to slip on primary fault
  - SKB report TR-08-11 did not provide sufficient description of the spatial and temporal evolution of stress magnitudes and orientations
  - Information needed to understand the calculated slip patterns

- How would shear deformation due to earthquake from a “blind” fault differ from the simulated case?
  - Many earthquake-generating faults do not cut ground surface, which leads to large displacement discontinuities near the fault tip
  - Model geometries with blind faults are likely to develop significantly different stress states in the target fracture region, which could alter the patterns of induced slip

Reviewer Recommendations to SSM (1 of 2)

- Provide information to show that ground motion time histories used for analysis of target fracture behavior are representative of ground motion time histories due to representative earthquakes
  - Systematic quantitative comparison of calculated and measured ground motion magnitudes and frequency, or
  - Analysis performed using representative ground motion time histories applied directly to a model of the target fracture region.

- Provide assessment of effects of potential fracture coalescence during seismic event on sizes and slip magnitudes of existing fractures
  - Evaluating effects of joining non-through-going fractures that are separated by rock bridges likely to fail during a potential earthquake

Reviewer Recommendations to SSM (2 of 2)

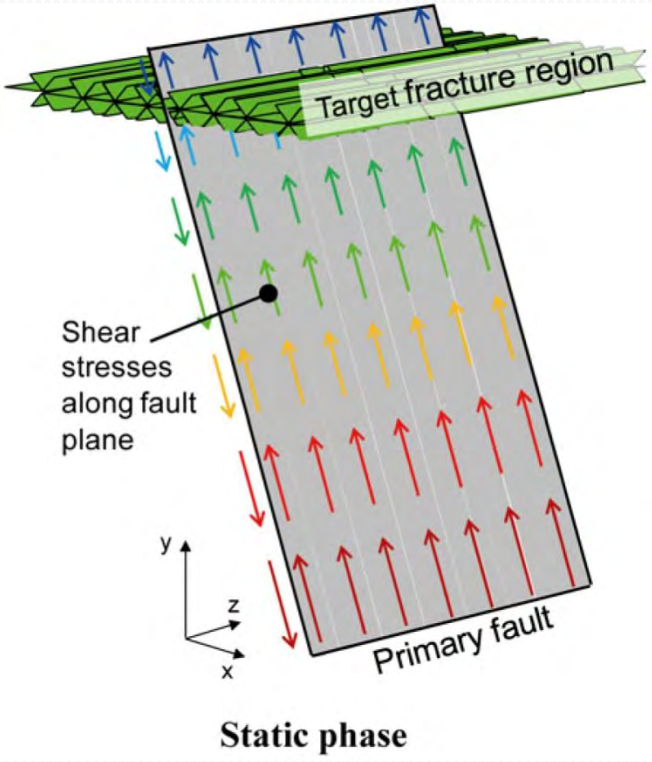
- Provide greater description of stress state evolution (orientations and magnitudes) in target fracture region due to primary fault slip
  - Temporal and spatial stress distributions control the induced slip that develops on existing fractures

- Provide analyses that include a geometrically blind (non-emergent) primary fault
  - Subsurface stress state evolution with a blind fault geometry and corresponding displacement gradient at fault slip may be significantly different from current models and may lead to revised interpretations of the induced slip patterns in the target fracture region

Backup Slides

SKB Geomechanical Modeling: Initial Static Equilibrium

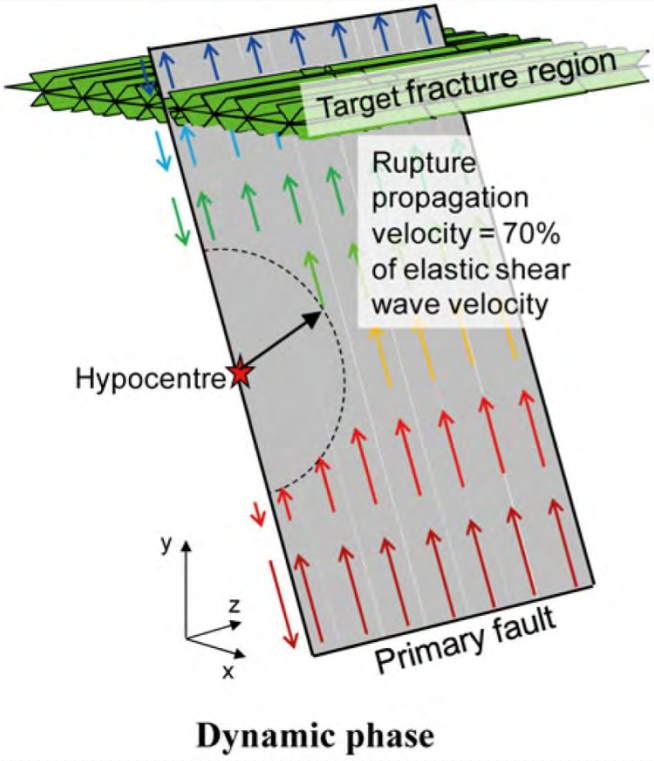
- Model subjected to gravitational loading balanced by initial stress
  - Initial stress setup to induce reverse-style faulting
  - Major principal stress horizontal and normal to fault plane
  - Intermediate principal stress horizontal and along fault strike
  - Minor principal stress vertical
- Typical of earthquakes due to post-glacial faulting in Swedish bedrock
- Major principal stress calibrated to give average fault slip for intended seismic moment
- Shear strength of fault surface assigned to prevent slip



Fälth et al. (2010), SKB TR-08-11, Figure 4-4a, p. 41.

SKB Geomechanical Modeling: Dynamic Phase

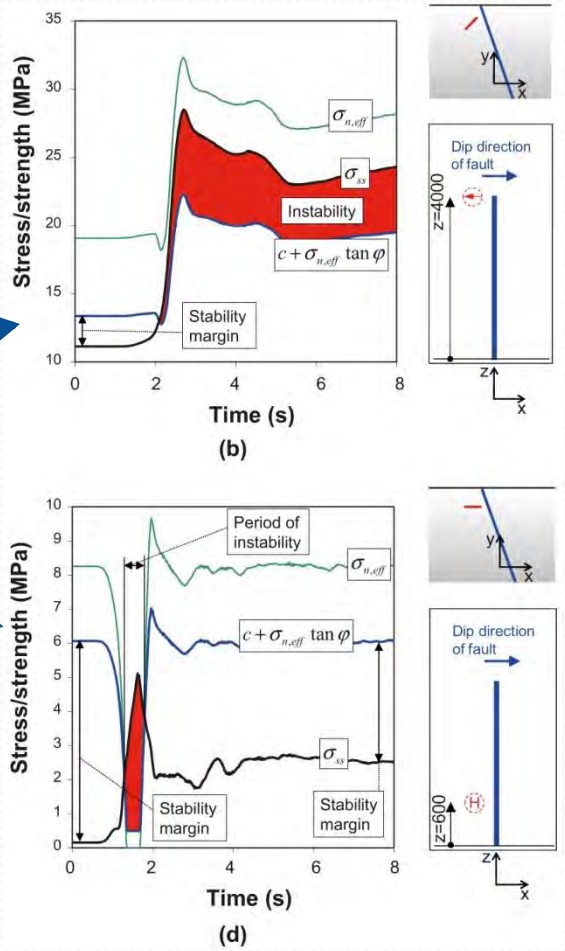
- Dynamic initiation and propagation of slip rupture on primary fault
  - Rupture initiated by decreasing shear resistance to zero (or small residual value) at selected hypocenter
  - Rupture propagated at selected speed through fault surface
  - Fault geometry, initial stress, and rate of shear strength reduction were controlled to vary the moment magnitude and stress drop of simulated earthquake
- Dynamic propagation of ground motion and stress waves through model domain
- Monitored time-dependent response of target fractures



Fälth et al. (2010), SKB TR-08-11, Figure 4-4b, p. 41.

SKB's Calculated Fracture Behavior: Fracture Stability

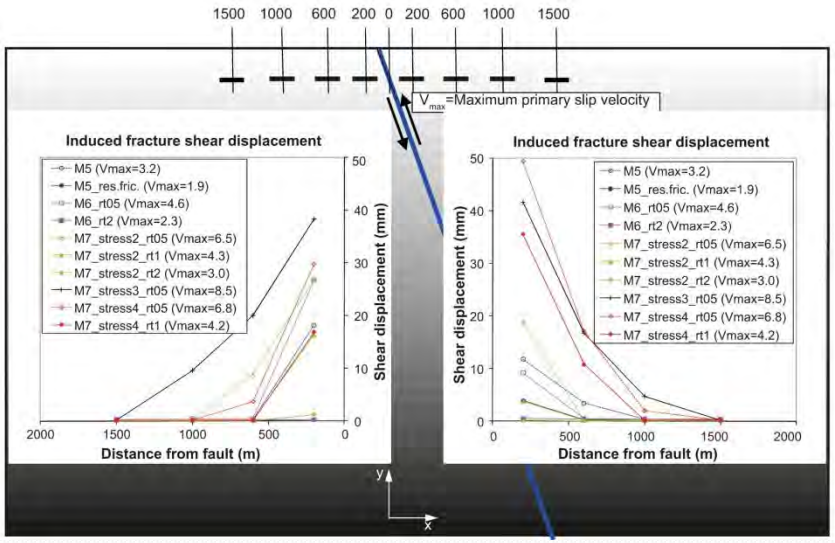
- Simulated seismic events caused slip on variously oriented fractures in the hanging wall and footwall sides of the fault
- Unstable stress states occurred on some fractures close to the fault edge and persisted beyond the seismic event
- Stress condition on some fractures was unstable for a short time during the seismic event but returned to stable thereafter
- Stability conditions on fractures in the footwall evolved differently than for fractures in the hanging wall



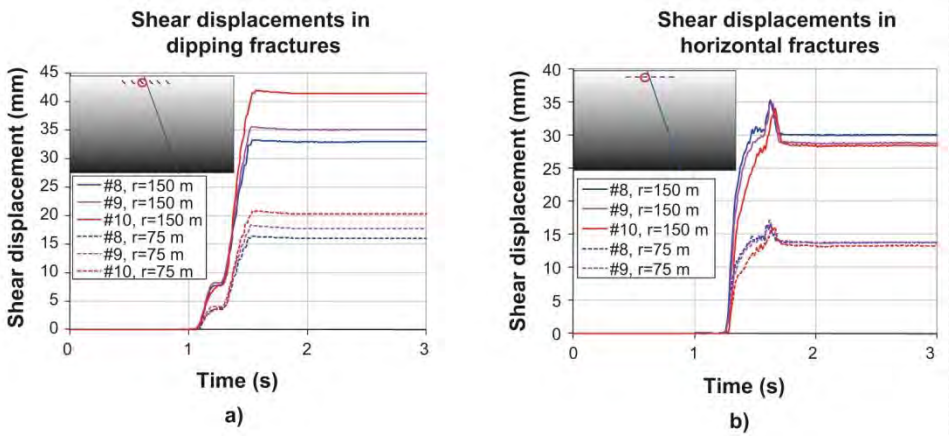
Fälth et al. (2010), SKB TR-08-11, Figure 5-13b and 5-13d, p. 72.

SKB's Calculated Fracture Behavior: Slip Magnitudes

- Slip magnitude decreases as distance from fault increases
- Slip magnitude increases linearly with fracture size
- Slip velocity correlates linearly with slip magnitude
- Calculated slip for 150 m radius model fractures can be scaled linearly to determine the induced slip for fractures of arbitrary size



Fälth et al. (2010), SKB TR-08-11, Figure 5-22, p. 82.

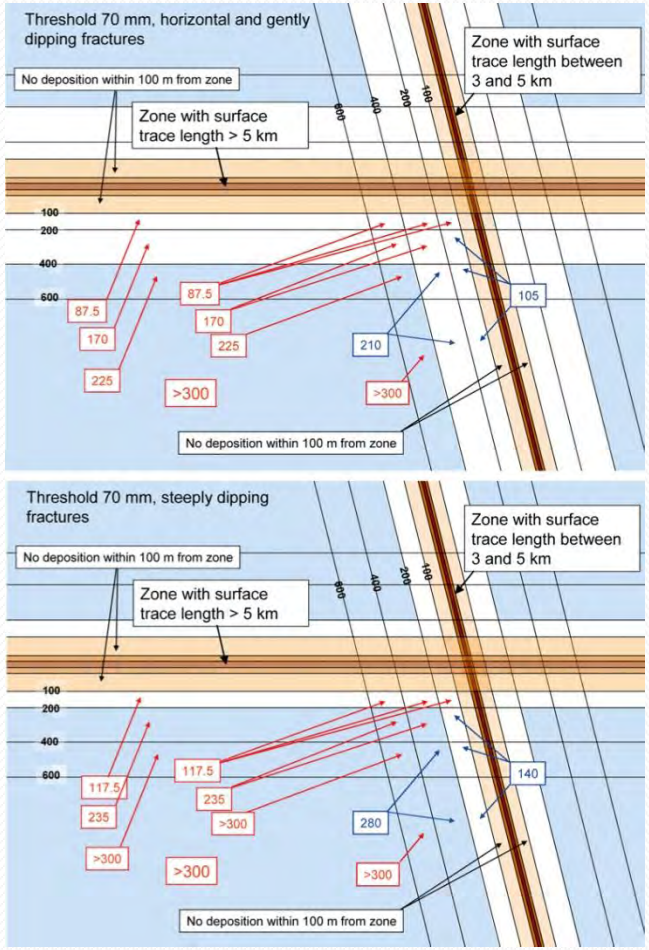


Fälth et al. (2010), SKB TR-08-11, Figure 5-36, p. 94.

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SKB's Proposed Respect Distances from Known Faults

- Based on avoiding fractures that could slip 50 mm or more during a potential earthquake
- Each respect distance range is associated with a critical fracture radius (blue and red rectangles)
- Fractures smaller than critical will undergo smaller than 50 mm slip
- Deposition holes should not intersect critical or larger fractures
- Probability of canister damage due to shear displacement can be calculated for deposition holes that intersect critical or larger fractures



Fälth et al. (2010), SKB TR-08-11, Figure 7-3, p. 121.