Path Forward: Research Directions and Plans for a PEER Research Project

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Probabilistic Approach

- Similar approach to hazard for ground motion
- Differences
  - Use disp(M|surface rupture) relation in place of ground-motion model
  - Include two additional terms for main rupture
    - Probability of surface rupture
    - Probability of rupture at the location of the site (along strike)
  - Include an additional term for secondary ruptures
    - Probability of secondary rupture at the site (finite foundation dimension)
    - Amplitude of the secondary rupture displacement given the main trace displacement

Examples of Current Models & Methods Used in CA

- Well and Coppersmith (1994)
  - Disp(M) models
- Youngs et al (2003)
  - Probabilistic rupture hazard methodology
- SFPUC report (2008)
  - Non-ergodic rupture hazard
- Petersen et al (2011)
  - Probabilistic rupture hazard for SS faults
  - Main and secondary rupture
- Moss et al (2011)
  - Probabilistic rupture hazard for REV faults
- Hecker et al (2013)
  - Evaluation of variability of slip at a point (from multiple earthquakes)
  - Basis for the non-ergodic surface slip model

Moving PFDHA Forward

- Objective
  - Develop a suite of alternative models for primary and secondary surface rupture for use in PFDHA
    - Key focus is for the secondary rupture
  - Models applicable to western US
  - Models should be widely accepted for engineering application

PEER Approach Used for Ground-Motions Projects

- Coordinated program of data collection and review to compile a high quality data base
    - Compile existing data
    - Identify key data gaps for development of surface rupture models
    - Focused new data collection to address key data gaps
    - Consistent treatment of data
    - Reviews of rupture data and meta data
    - Interaction with model developers for parameters in the data base
- Use of existing analytical modeling methods
    - Develop constraints for the models outside the range well constrained by the empirical data
- Development of set of models for engineering applications
    - Multiple groups develop models
    - Frequent interaction during the model development
    - Peer review
        - Comparisons between models during the model development
        - Trial applications during model development

PEER Fault Rupture Hazard Project

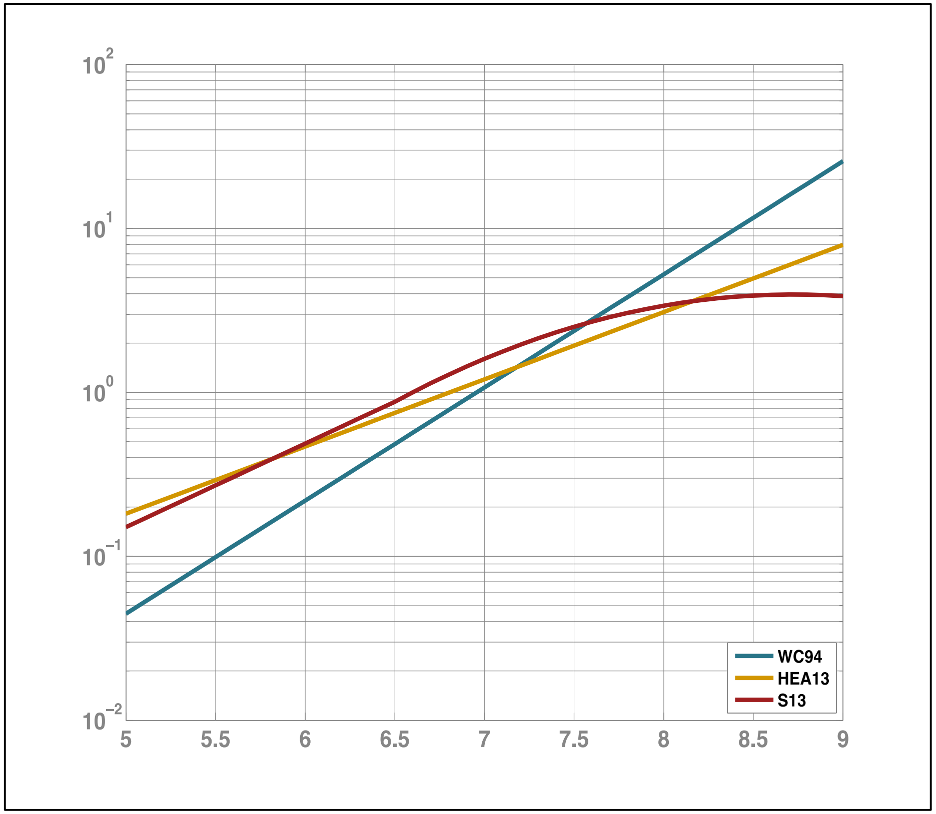
- Objectives
  - Address the surface rupture amplitude models for primary and secondary ruptures
    - Source characterization not addressed
  - Develop a suite of alternative models for primary and secondary surface rupture for use in PFDHA
    - Models applicable to western US
    - Models widely accepted for engineering application
- Does not replace research on fault rupture
  - Snapshot in time of the summary of science

Key Issues

- Initial set of issues for current methods for surface rupture models for use in PFDHA
  - Non-Erogdic
  - Site Effects
  - Secondary Ruptures
  - Physical constraints from analytical models
  - Statistical Models & Assumptions

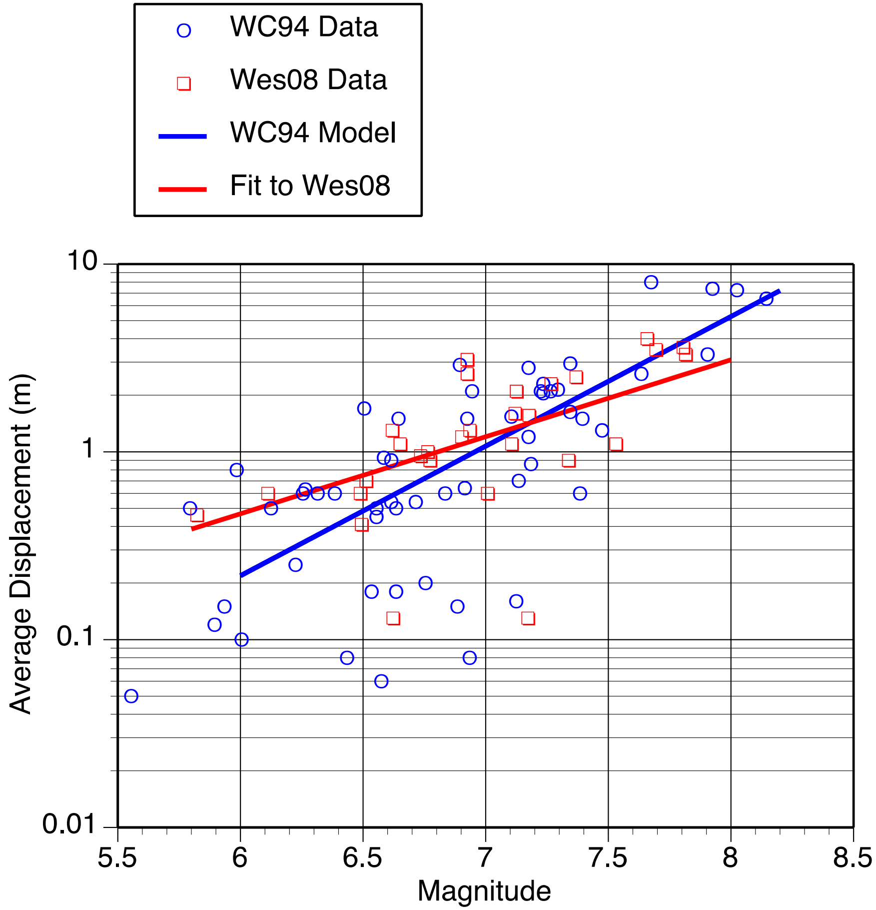
Ergodic Surface Rupture Models

- Most Disp(M) models are based on global data
  - Standard Deviation is large
    - 0.35 (log10) for Ave Disp
    - 0.6 CV for along strike
    - Total CV about 1.0
- Variability of slip at a point is much smaller
  - CV = 0.4 – 0.55 (Hecker et al, 2013)

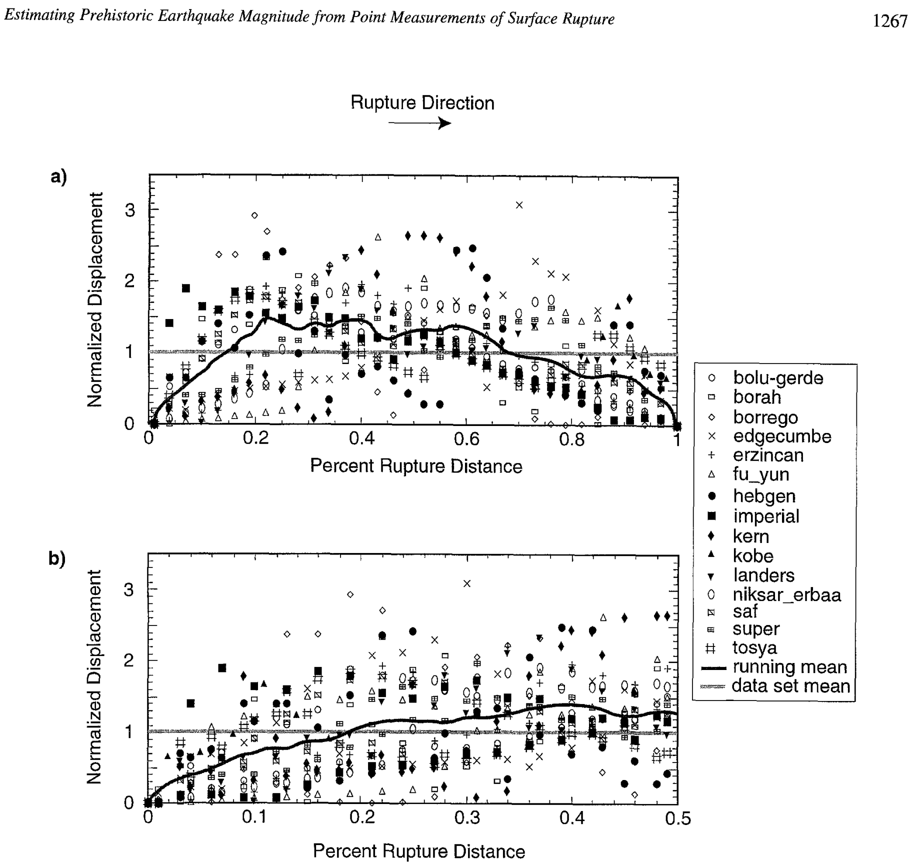


Global models (Ergodic)

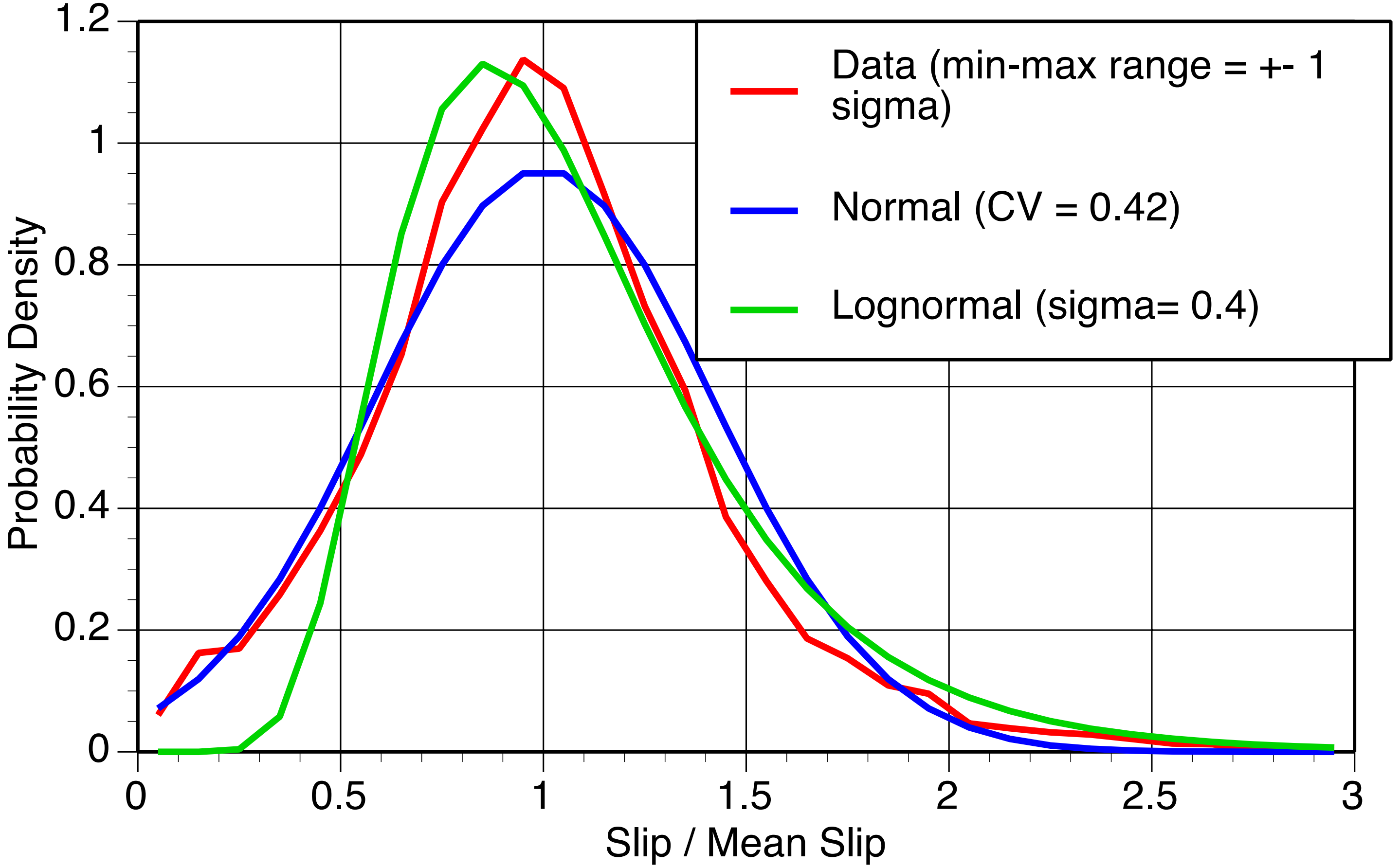
Aleatory Variability of Ave Disp

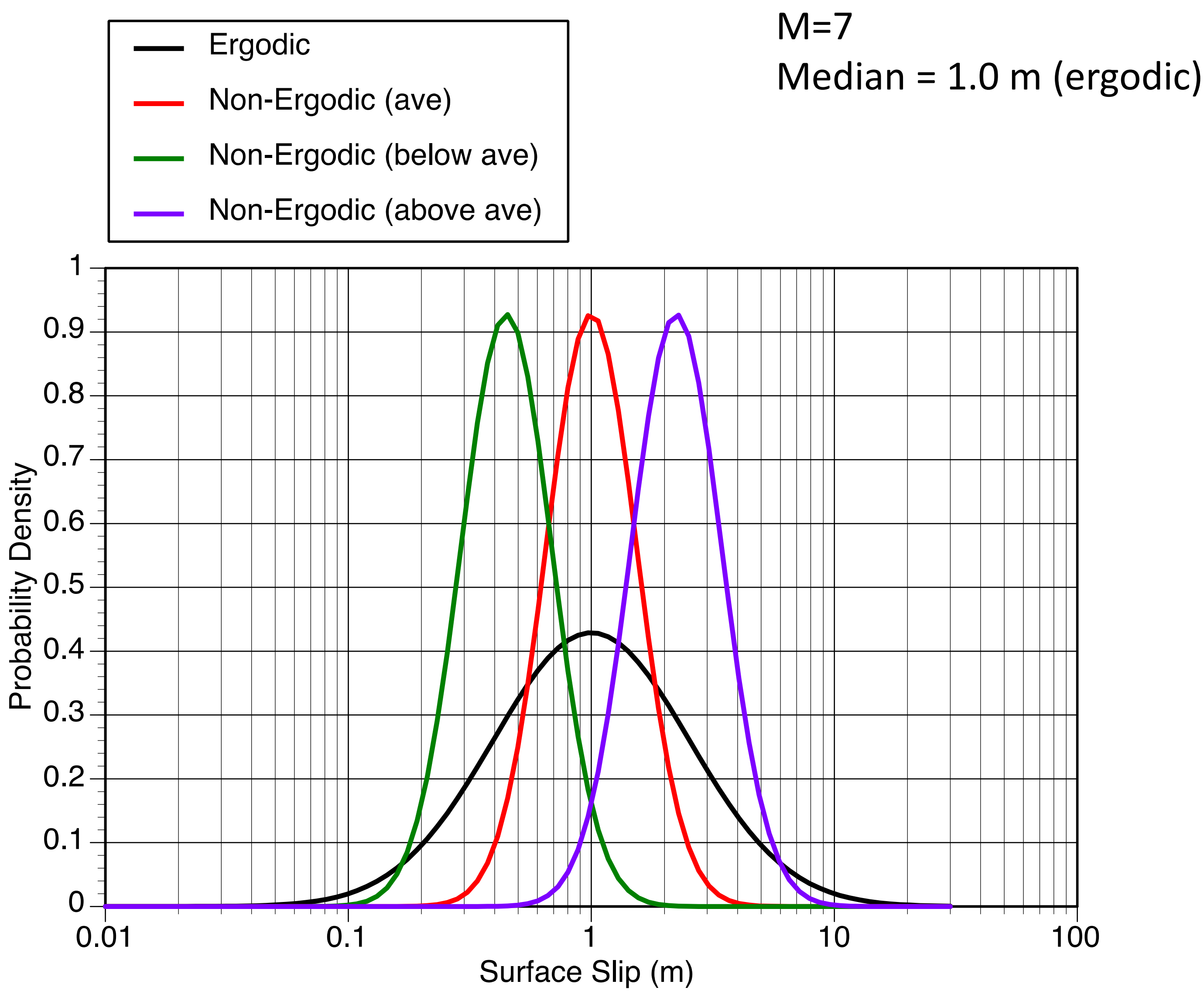


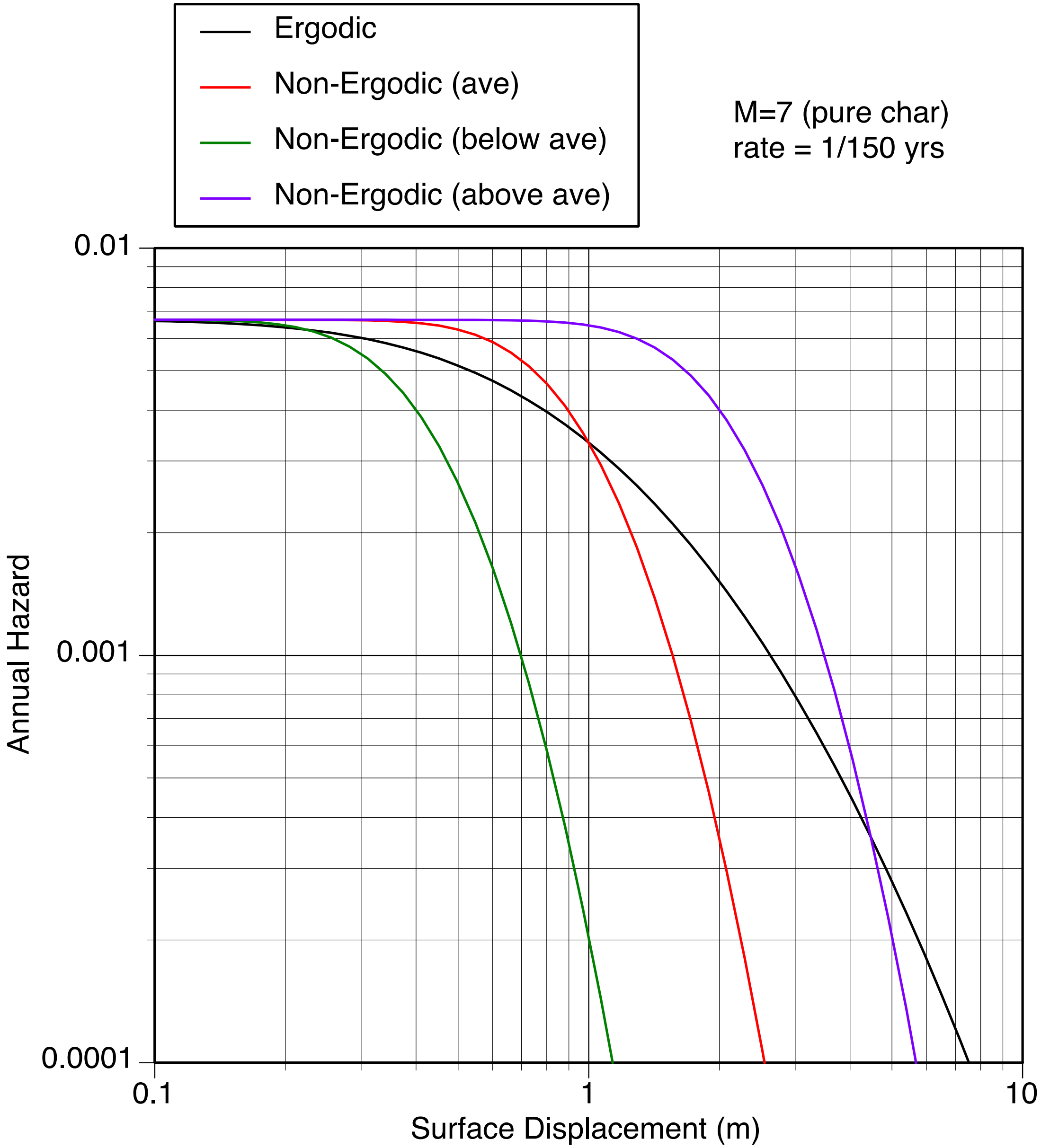
Aleatory Variability of of Slip Along the Rupture



Aleatory Variability of Slip at a Point from sites with multiple earthquakes (Hecker et al 2013)




Ergodic
Non-Ergodic (ave)
Non-Ergodic (below ave)
Non-Ergodic (above ave)
M=7
Median = 1.0 m (ergodic)
Probability Density
Surface Slip (m)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0.01
0.1
1
10
100


Ergodic
Non-Ergodic (ave)
Non-Ergodic (below ave)
Non-Ergodic (above ave)
M=7 (pure char)
rate = 1/150 yrs
0.01
0.001
0.0001
Annual Hazard
0.1
1
10
Surface Displacement (m)

Site Effects

- Site effects are not in current Disp(M) models
  - Site effects expected to have an effect on the surface rupture
- Site conditions are not compiled in the existing data sets
  - Need to go back and collect site conditions for the complete data base
- Geotechnical models
  - Compile existing geotechnical data from lab testing and field observations soil effects on ruptures
  - Develop statistical models for analytical constraints

Secondary Ruptures

- Limited models available
    - Strike-slip model by Petersen et al (2011)
- Limited empirical data
    - Hard to constrain the empirical model for all the different cases
        - Magnitude
        - Distance from mapped trace
        - Fault type (SS, RV, NML)
        - Fault complexity

Secondary Ruptures

- Can be important for structures sensitive to small deformations from secondary ruptures
  - Gas and water pipelines
    - Designed for displacement at primary rupture fault
    - Typically no consideration for deformation from secondary ruptures
  - Concrete dams
    - Primary rupture through dam not allowed
    - Secondary ruptures not clear rules
  - Bridges
    - Focus on main rupture, but with uncertainty in the location (where could the rupture occur under the bridge)
  - High Speed Rail
    - Sensitive to small deformations for train operations
    - Secondary ruptures may be important issue

Physical Constraints

- Issue: Extrapolation of limited empirical data
  - Get into problems when extrapolating models without constraints
- Candidate physical models
  - Dynamic rupture models
    - Distribution of stress, modulus of crust, and Friction law
    - self propagating ruptures
- Secondary ruptures
  - Use distribution of weak zones in the crust
  - Compute the surface rupture for large set of secondary ruptures scenarios
  - Develop constraints on the scaling based on the large suite of simulations
  - Apply constraints to empirical models
- Site effects
  - Including site conditions in dynamic rupture models or using geotechnical modeling of site effects

Statistical Methods & Assumptions

- Standard assumptions
  - Log-normal distribution for most Disp(M) models
  - Normal distribution for variability along strike
  - Neither works well for tails
  - Alternative distribution (e.g. beta) needed
- Correlation
  - Data typically assumed to be independent
  - Closely spaced measurements are correlated
    - Often more measurements in the high slip regions
    - Affects the estimates of the average slip
- Approaches
  - Seismology models for slip distribution on the fault plane use statistical models developed in the wavenumber domain
  - May be a useful approach for surface rupture

Development of Fault Rupture Models for PFDHA

- Years 1-2
  - Empirical data base
    - Compile existing surface rupture data
    - Collect site condition information for past rupture data sets
    - Collect new rupture data to address data gaps
  - Analytical Modeling
    - Testing of dynamic rupture methods for secondary ruptures
    - Application of validated methods for constraining scaling in empirical surface rupture model
    - Comparison with distributions from seismological approaches for slip models (full fault, not just the surface)

Development of Fault Rupture Models for PFDHA

- Years 1-2
  - Geotechnical Modeling of site effects on surface rupture
    - Compile/parameterize existing geotechnical studies
    - Develop constraints on site effects
  - Statistical Methods
    - Evaluation of statistical distributions for surface rupture
    - Include effects of spatial correlations in statistical methods
- Year 3
  - Develop surface rupture models for both primary and secondary ruptures for engineering applications
    - Functions of Magnitude, dip, style-of-faulting, fault complexity, ….

Draft Costs = $3.5M over 3 Yrs

Task		Yr 1	Yr 2	Yr 3
Compilation & review of existing surface rupture data	2 post docs	250	250	125
Collection of New surface rupture data and site condition data	Address data gaps	300	600	
Surface rupture database development		100	100	
Review of database	external		50	
Numerical simulations for secondary ruptures	2 methods	300	150	
Geotechnical modeling of site effects on surface rupture	Grad student	80	80	80
Statistical methods/models for surface ruptures			50	50
Rupture model development (primary and secondary ruptures; probability of surface rupture)	4 models (2 paid, 2 unpaid)	50	50	200
Open source program for probabilistic rupture hazard (including non-ergodic approach)		20	20	50
Trial applications (identified by sponsors)	Funded by sponsors			
Project Advisory Panel	External & sponsors	25	25	25
Management costs	15%	170	205	80
Total		1295	1580	610

International Collaboration

- Researchers
  - Specific tasks (data collection) works well
  - Model developers
    - Requires significant interaction (monthly to quarterly)
- Funding Partners
  - Coordinate tasks and have separate funding sources
  - International collaborators fund research in their own countries, but the tasks are coordinated so that the results fit into the larger project

Potential for Funding from Stakeholders

- Incentive for stakeholders
  - Uncertainties in current rupture models are so large that is is difficult to make risk-informed decisions
  - Good science is good business
- What works
  - To be successful, need to have a champion within the stakeholder organization
  - Ideal to be able to run trial applications
    - Helps to get stakeholders engaged