Geostatistics for modeling of soil spatial variability in Adapazari, Turkey

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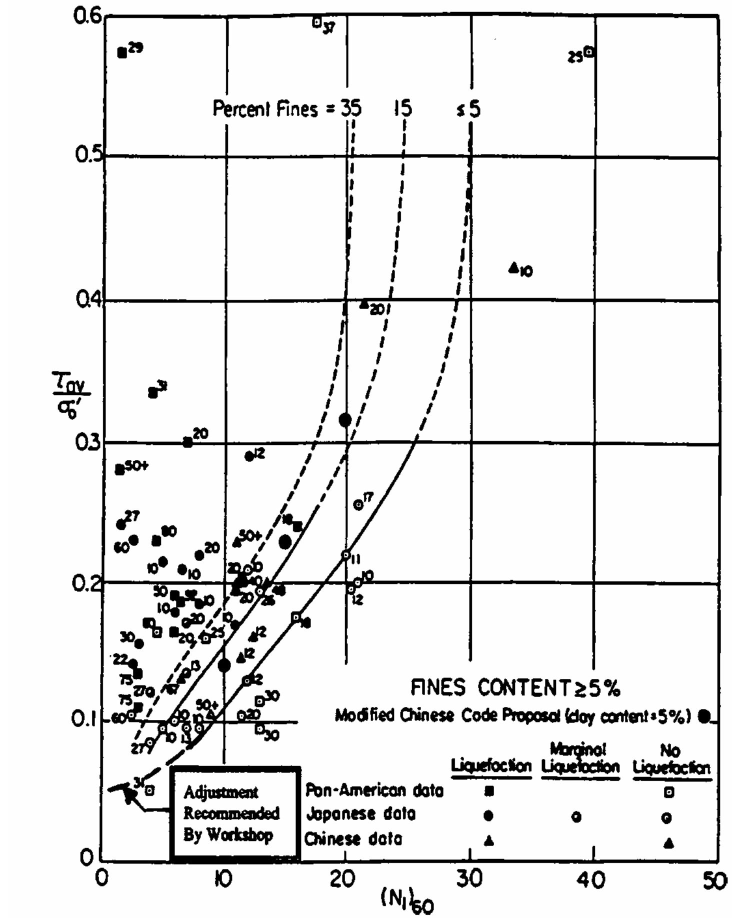
Practical evaluation of liquefaction occurrence

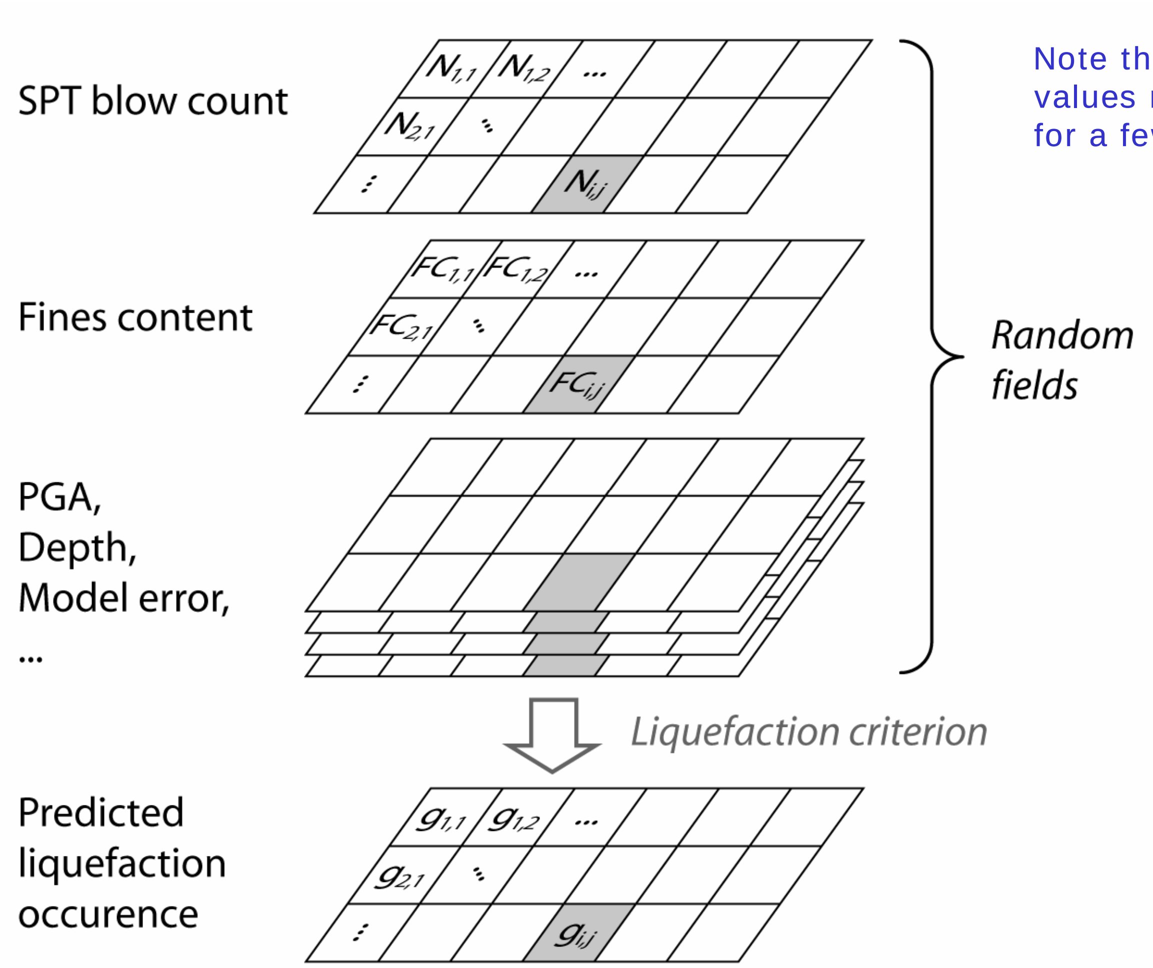
- Obtained from empirical observations
- Useful for practical evaluations
- Applied only at single locations

(from Seed et al.)



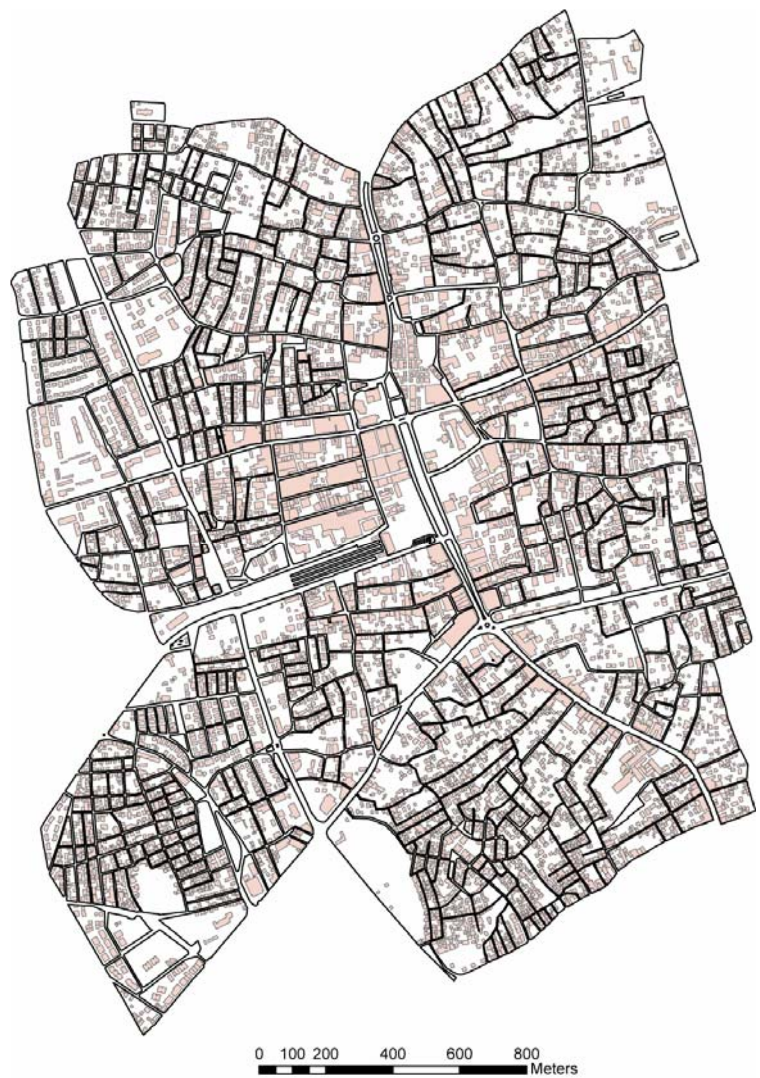
An approach is proposed here for incorporating spatial dependence of soil properties to evaluate the potential spatial extent of liquefaction

Proposed procedure for evaluating liquefaction extent



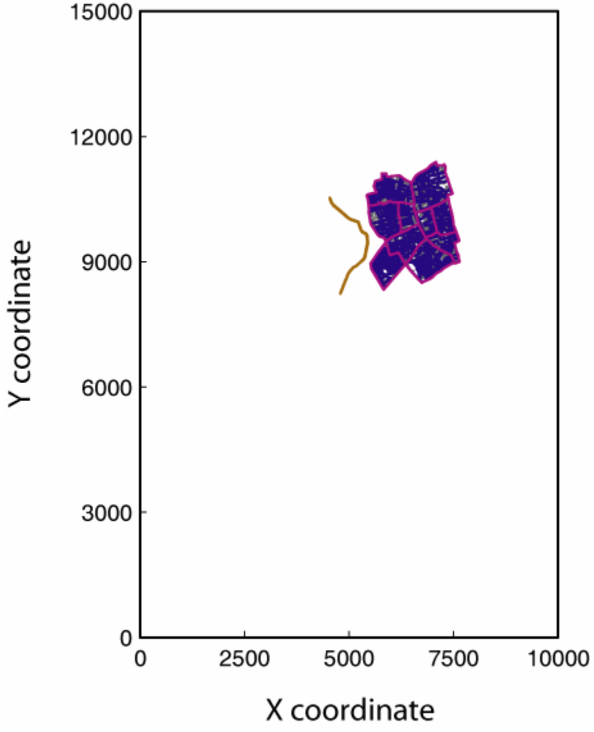
Note that soil property values may be available for a few locations

A demonstration site in Adapazari, Turkey

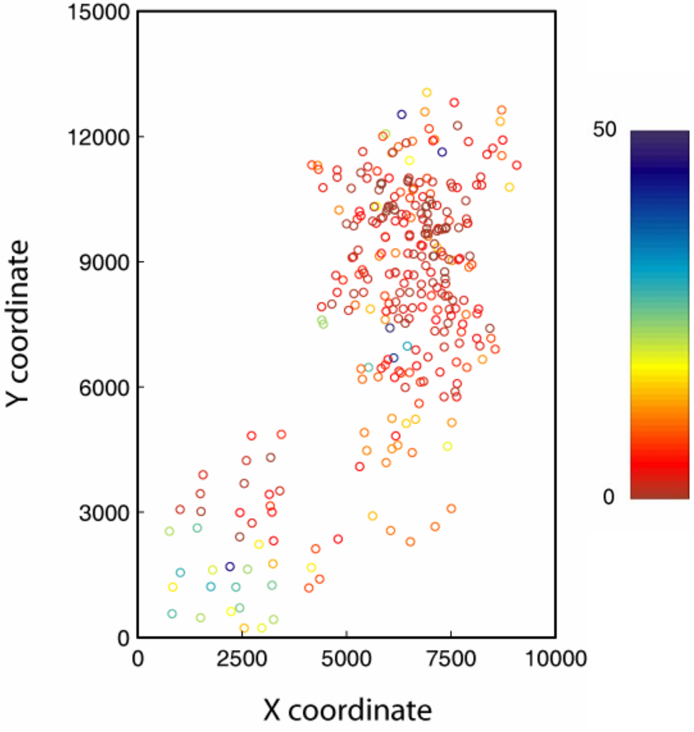


Sampled $N_{1,60}$ values near the demonstration site in Adapazari, Turkey

Test site



Sampled soil values



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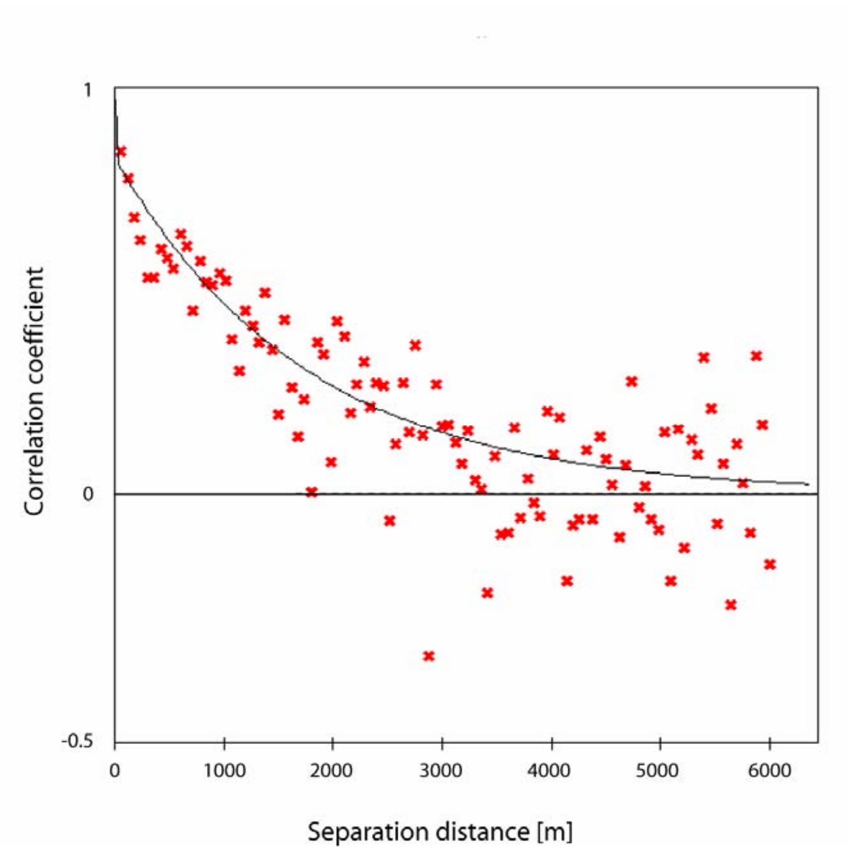
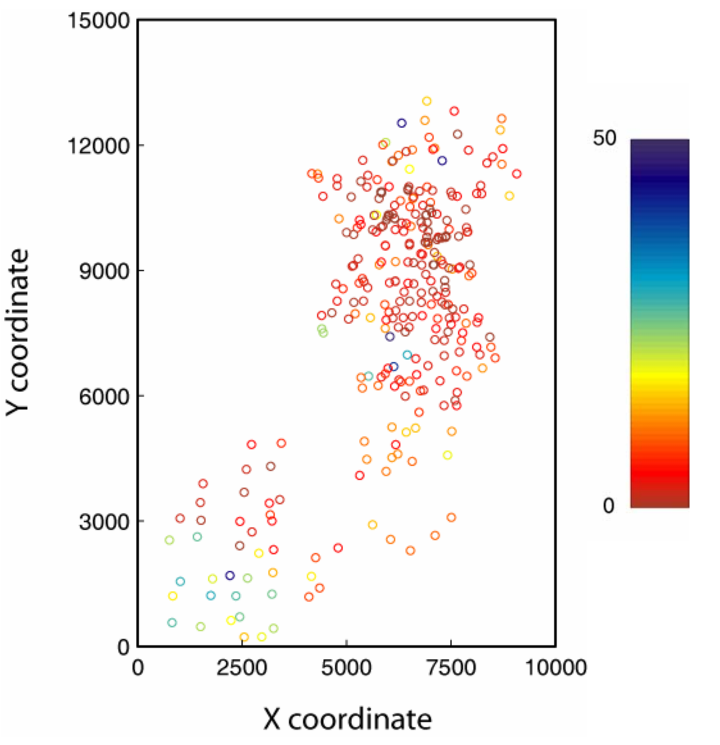
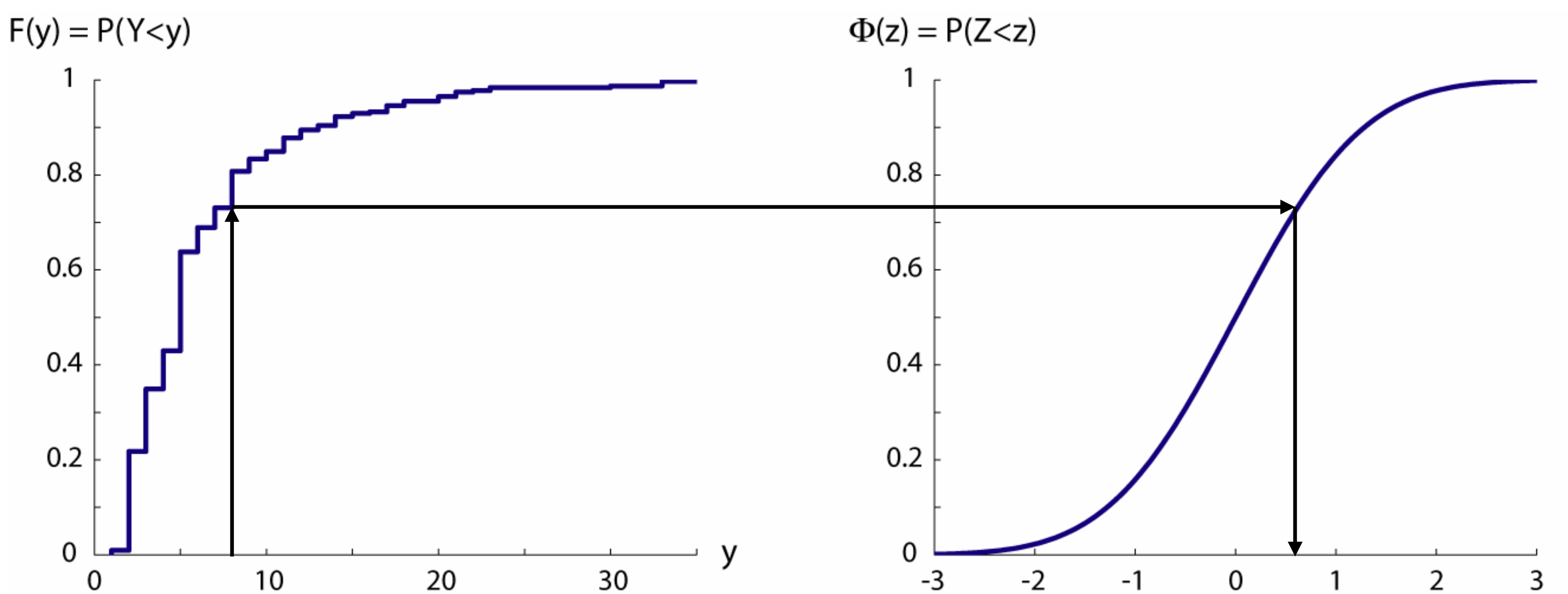




$$\rho(h)=0.85\left[1-\exp\left(\frac{h}{5000}\right)\right]$$

Simulation of $N_{1,60}$ values, conditional on observations (*Sequential Gaussian Simulation*)

1. Transform data so that it is normally distributed: $z=\Phi^{-1}\left(F(y)\right)$



Empirical CDF of $N_{1,60}$ values

Standard normal CDF

Simulation of $N_{1,60}$ values, conditional on observations (*Sequential Gaussian Simulation*)

2. Estimate spatial dependence of soil properties

$$\rho(h) = 0.85\left[1 - \exp\left(\frac{h}{5000}\right)\right]$$

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2. Estimate spatial dependence of soil properties

$$\rho(h) = 0.85\left[1 - \exp\left(h / 5000\right)\right]$$

3. Simulate one additional point (Z_1), conditional upon observed values

$$\begin{bmatrix} Z_1 \\ \mathbf{Z}_{orig} \end{bmatrix} \sim N\left(\begin{bmatrix} 0 \\ \mathbf{0} \end{bmatrix}, \begin{bmatrix} 1 & \mathbf{\Sigma}_{12} \\ \mathbf{\Sigma}_{21} & \mathbf{\Sigma}_{22} \end{bmatrix}\right) \Rightarrow \left(Z_1 | \mathbf{Z}_{orig} = \mathbf{z}\right) \sim N\left(\mathbf{\Sigma}_{12} \cdot \mathbf{\Sigma}_{22}^{-1} \cdot \mathbf{z},\ 1 - \mathbf{\Sigma}_{12} \cdot \mathbf{\Sigma}_{22}^{-1} \cdot \mathbf{\Sigma}_{21}\right)$$

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4. Repeat step 3 for each location, treating previously simulated points as fixed

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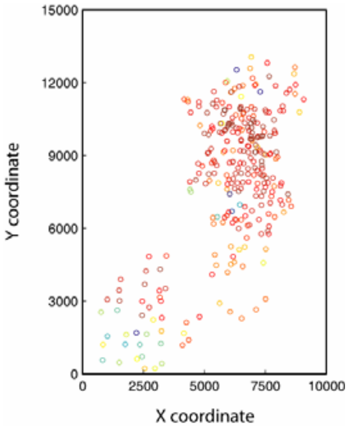
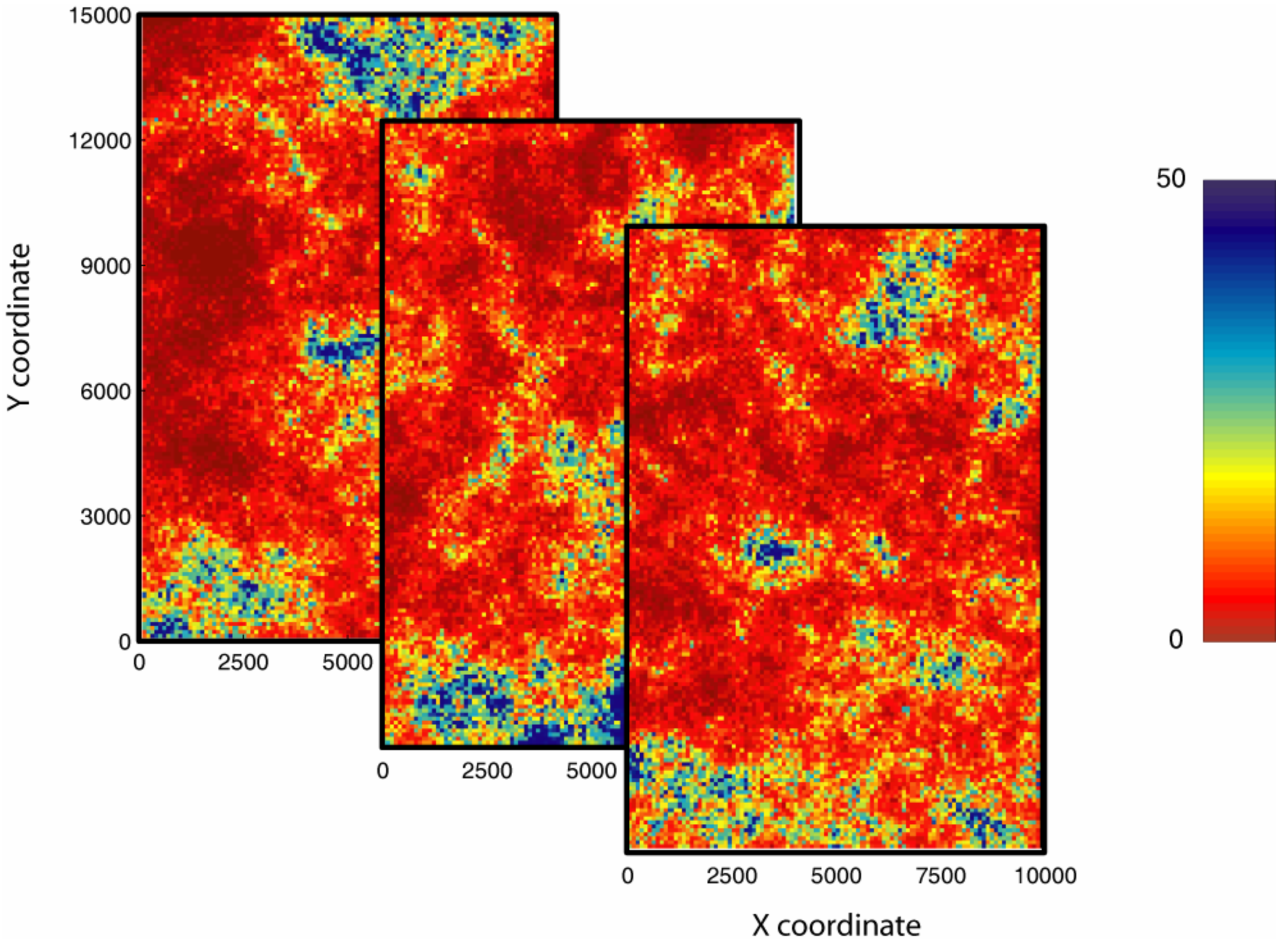
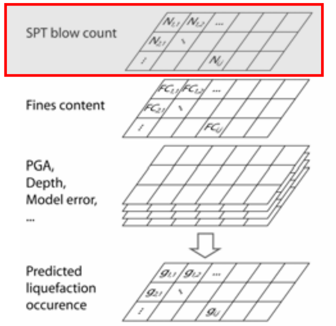
5. Transform the simulated Gaussian variables back to the original distribution

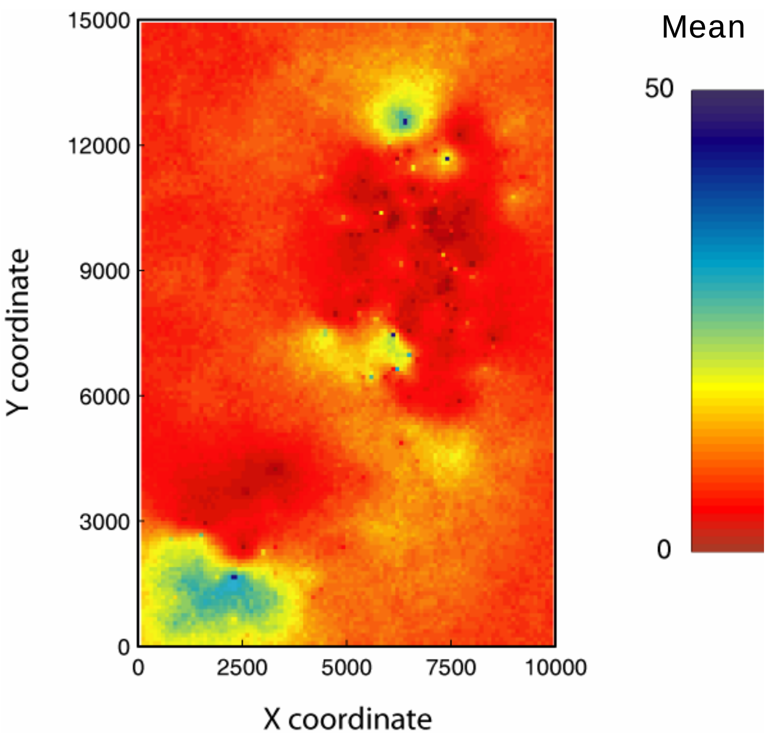
Conditional simulations of $N_{1,60}$

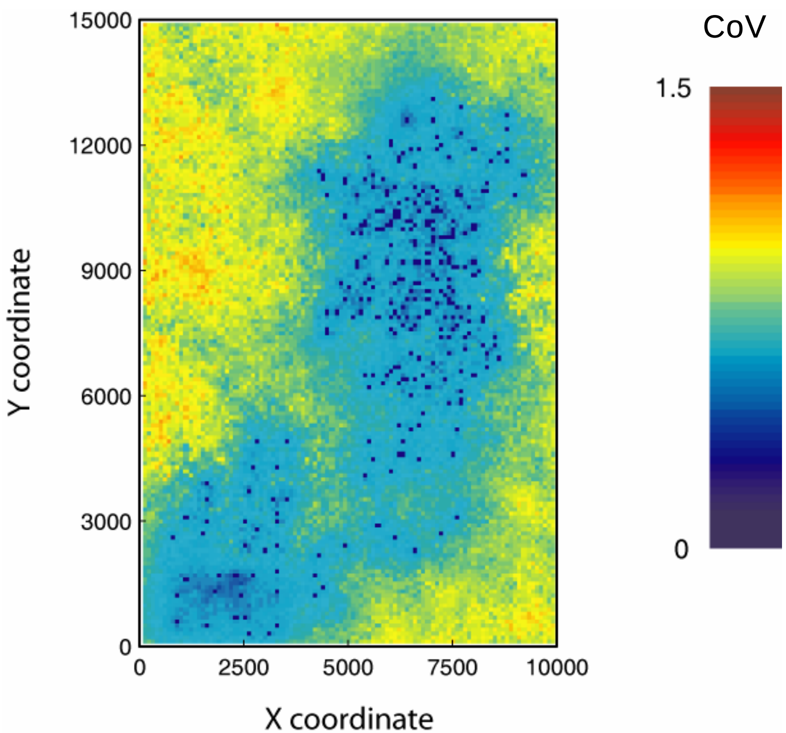






Mean and coefficient of variation of conditional $N_{1,60}$ simulations

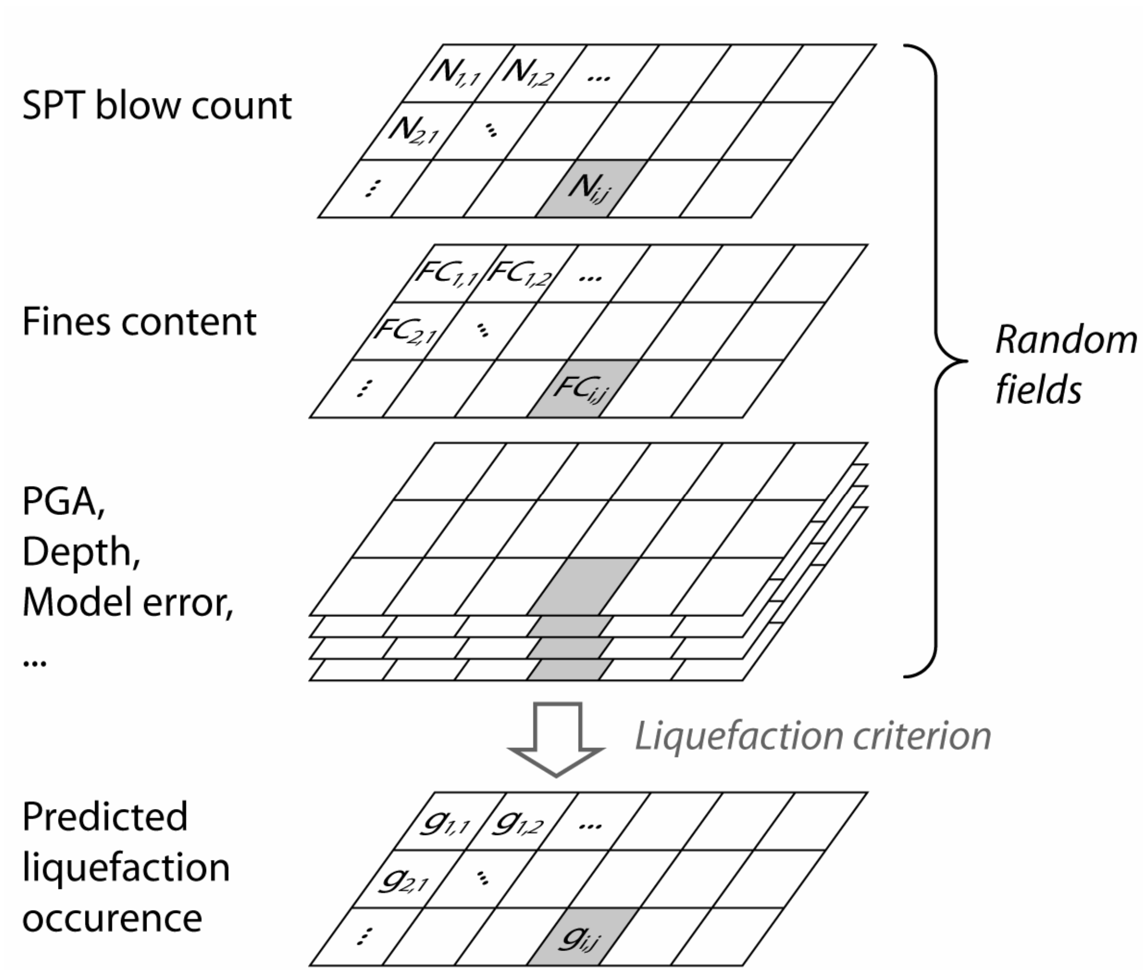




Comments on Sequential Gaussian Simulation

- Common in petroleum engineering and mining
- Requires jointly Gaussian random variables
  - Partially achieved using the normal score transform
  - This numerical transform is applicable for any probability distribution
- Can also be used for vectors of dependent parameters (e.g., SPT blow count and fines content)
- It is not necessary to condition on all previous points when simulating

Procedure for evaluating liquefaction extent



A probabilistic liquefaction criterion (Cetin et al., 2004)

$$g(\mathbf{X},\mathbf{u}) = N_{1,60}(1+0.004FC) - 13.32\ln CSR_{eq} - 29.53\ln M - 3.70\ln\frac{\sigma_v^{'}}{P_a} + 0.05FC + 44.97 + \varepsilon_L$$

$$CSR_{eq} = 0.65\left(\frac{PGA}{g}\right)\left(\frac{\sigma_v}{\sigma_v^{'}}\right)r_d$$

$$r_d = \frac{\left[1+\frac{-23.013+2.949a_{\max}+0.999M_w+0.0525V_{s,12\mathrm{m}}^{*}}{16.258+0.201e^{0.341(-d+0.0785V_{s,12\mathrm{m}}^{*}+7.586)}}\right]}{\left[1+\frac{-23.013+2.949a_{\max}+0.999M_w+0.0525V_{s,12\mathrm{m}}^{*}}{16.258+0.201e^{0.341(0.0785V_{s,12\mathrm{m}}^{*}+7.586)}}\right]} + \varepsilon_{r_d}$$

$$\sigma_{\varepsilon_{r_d}} = \begin{cases} d^{0.85}\cdot 0.0198 & \text{if } d \le 12\mathrm{m} \\ 12^{0.85}\cdot 0.0198 & \text{if } d > 12\mathrm{m} \end{cases}$$

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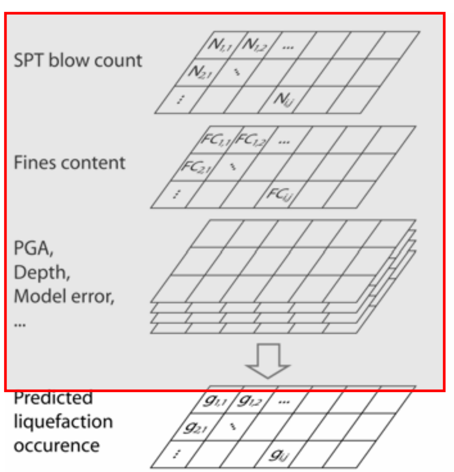
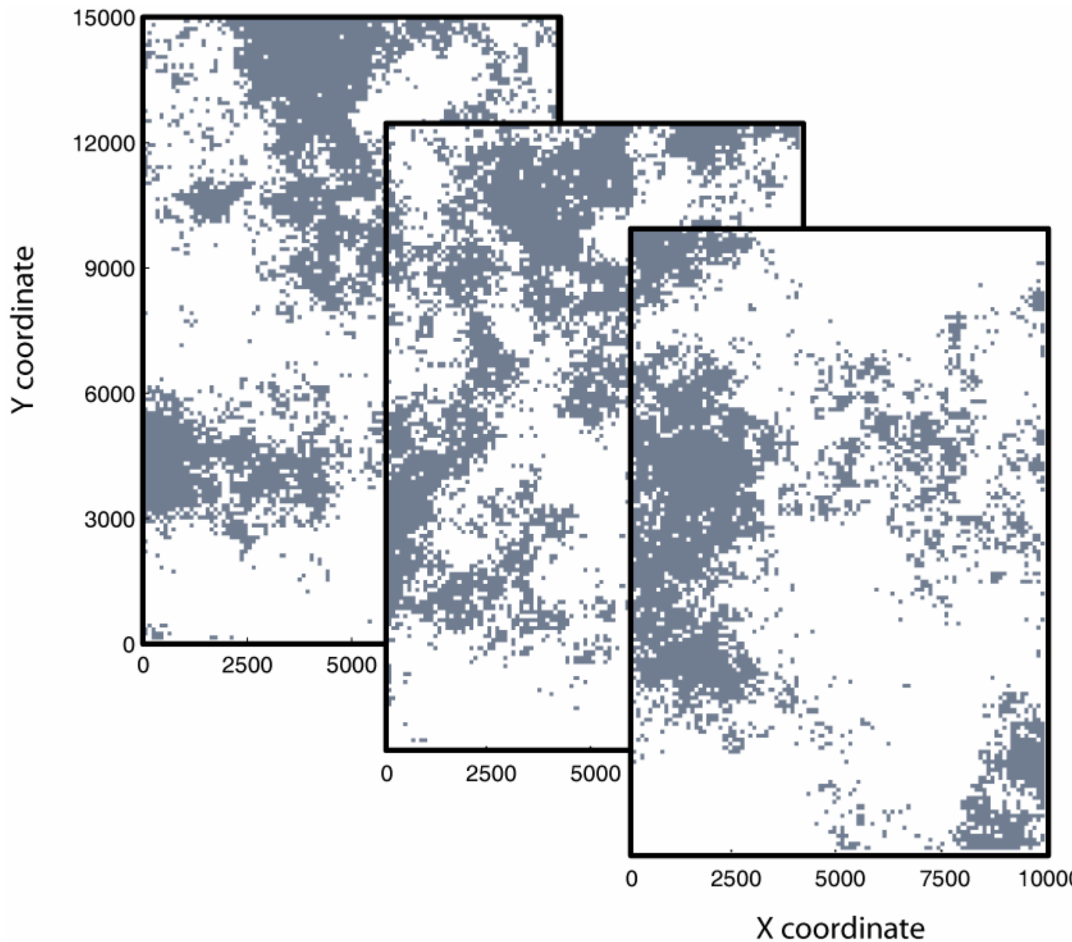
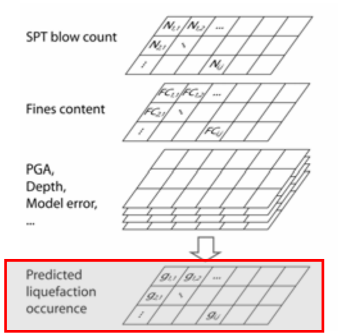
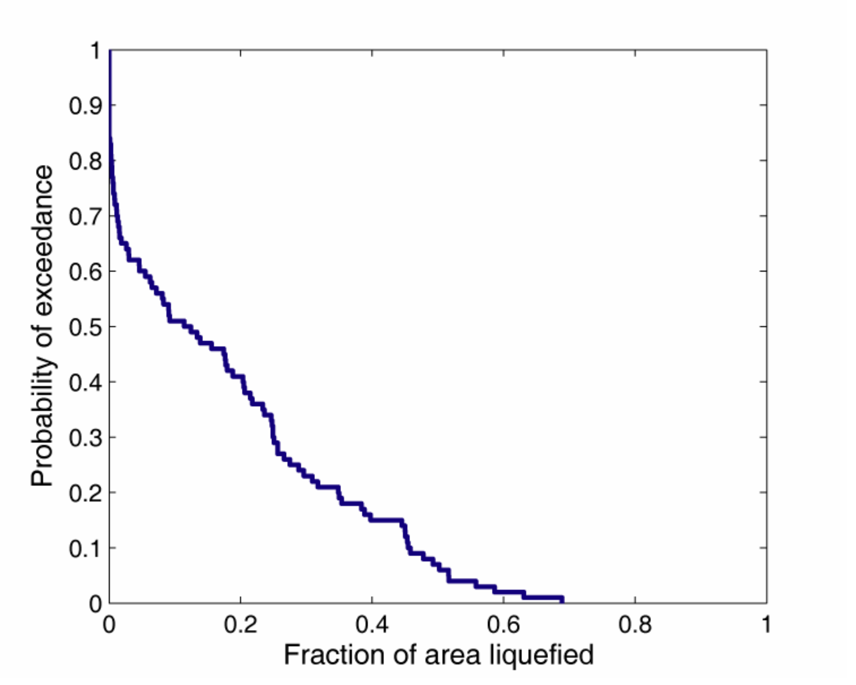


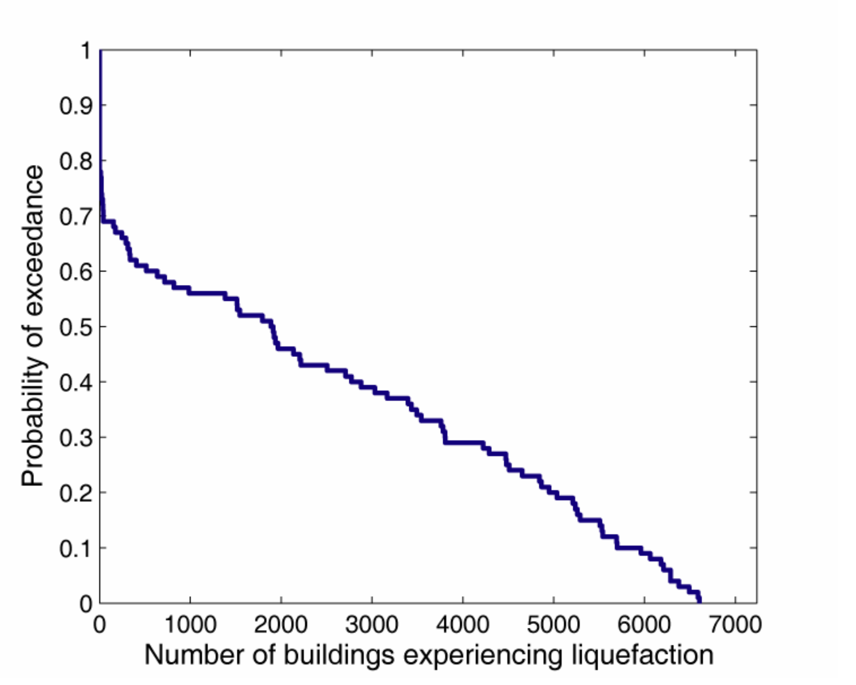
Realizations of liquefaction extent





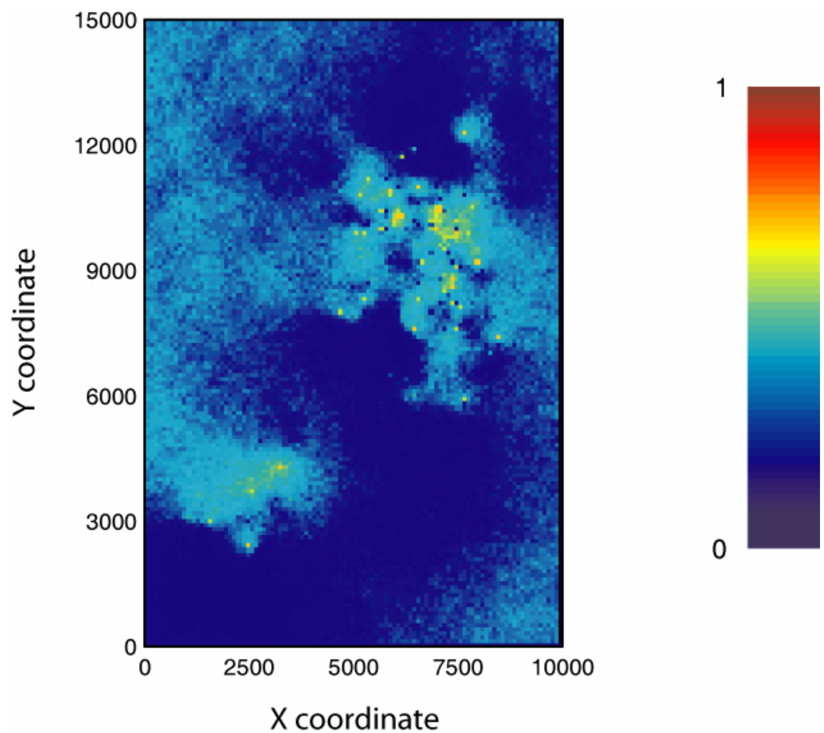
Probabilistic evaluation of consequences, given a M=7 earthquake causing a PGA of 0.3g



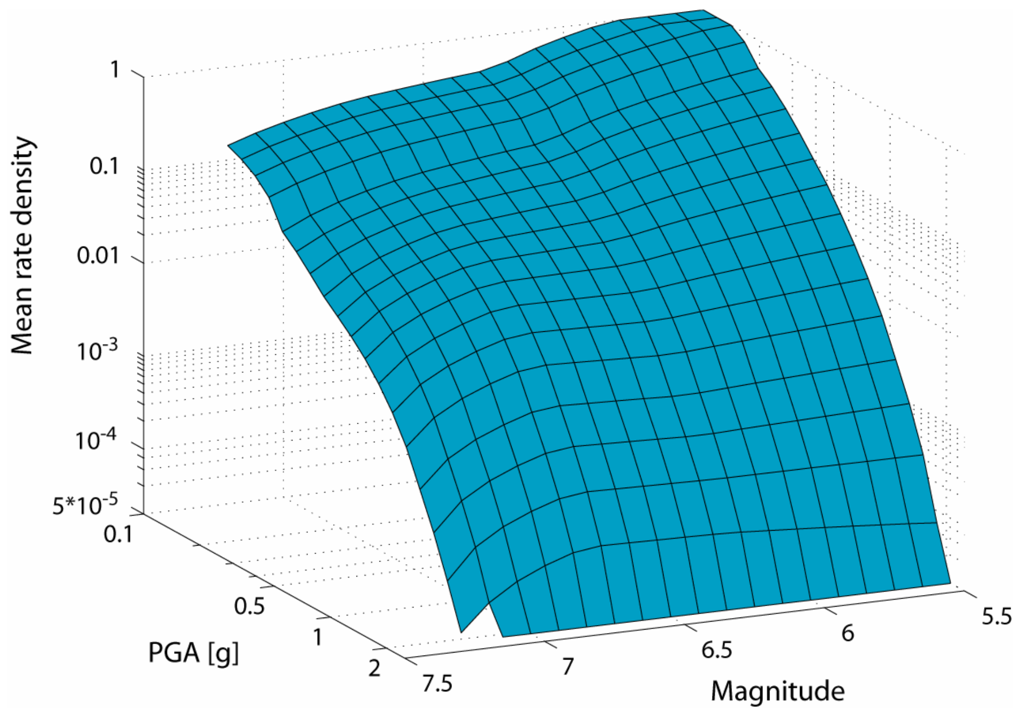


$$P(Y>y|\,pga,m)=\int_{\boldsymbol{\eta}} I\left(h\left(\mathbf{g}(\boldsymbol{\eta}|\,pga,m)>y\right)\right)\, f_{\boldsymbol{\eta}}(\mathbf{e})d\mathbf{e}$$

Probability of liquefaction at the study site, given a M=7.4 earthquake causing a PGA of 0.3g



The previously computed result for a deterministic loading case can be combined with stochastic loading obtained from probabilistic seismic hazard analysis (PSHA)



(see Baker and Faber, 2006)

Comments

- The procedure is useful for organizing the many pieces of relevant engineering data, but the inputs need careful consideration
- Soil random field models are challenging to characterize
  - Soil layering?
  - Unidentified local soil lenses?
  - Homogeneity/Ergodicity assumptions?
- Modeling post-liquefaction behavior is a challenge
- Geotechnical data often comes from several sources of varying quality

Conclusions

- A framework has been proposed for modeling the spatial extent of liquefaction
  - Accounts for spatial dependence of soil properties
  - Incorporates known values of soil properties at sampled locations
  - Complex functions of the spatial extent of liquefaction can be evaluated
- Probabilistic seismic hazard analysis can be used to incorporate all possible ground motion intensities
  - Avoids the use of a scenario load intensity with unknown recurrence rate
  - Provides an explicit estimate of annual occurrence probabilities
- This approach potentially allows for the design of projects with uniform levels of reliability