Energy-Based Liquefaction Evaluation Procedure

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QuakeCoRE Flagship 2: Liquefaction Impacts on Infrastructure

Advantages Over Stress-Based Procedure

- Primary mechanism of energy dissipation in sandy soils is frictional, resulting from particles rubbing against each other as the sand skeleton breaks down due to earthquake shaking
  - Correlations developed from cyclic laboratory test results relating dissipated energy to excess pore water pressures
- Macro fatigue theories already exist which use dissipated energy as the damage metric
  - Not reinventing the wheel, but rather just modifying existing (mature) mechanical frameworks
  - More firmly founded in mechanics than the semi-empirical stress-based procedures, which will allow the procedures to be extrapolated to scenarios not well represented in the liquefaction case history database
  - Don't need as many empirical "add-on" factors (e.g., MSF, K_σ, K_{DR}, …)

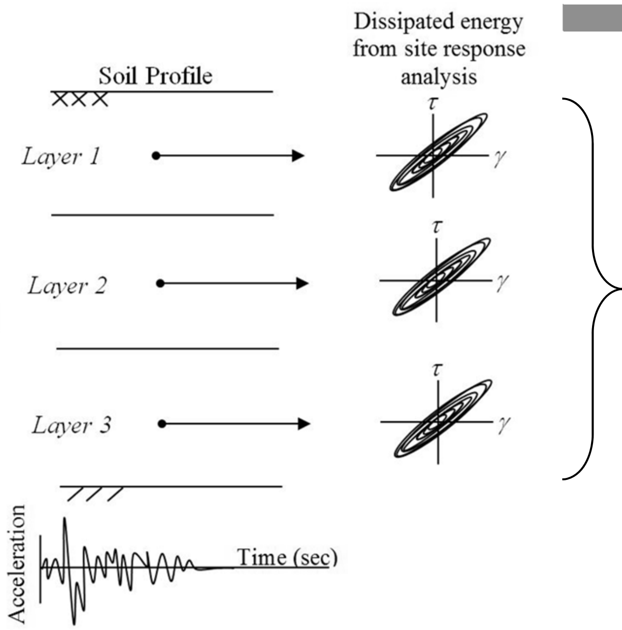
Advantages Over Stress-Based Procedure (cont.)

- Loading does not necessarily have to be earthquake shaking (e.g., blast loading, vibroseis, etc.)

Desired Characteristics of Energy-Based Liquefaction Procedure

- Required input shouldn't be onerous
  - Specification of earthquake motions should be inline with how design earthquake motions are currently specified for liquefaction evaluations (e.g., Mw and PGA)
  - Should be able to accommodate more refined characterization of earthquake motions (e.g., acceleration time series)
  - Soil characterization should be in terms of common index parameters (e.g., SPT N-value, CPT tip resistance and sleeve friction, Vs, etc.)
- Implementation should "feel" familiar to practicing engineers
  - Format should be similar to the simplified liquefaction evaluation procedure
  - Implementation shouldn't be too complex
- Should have both deterministic and probabilistic forms (full quantification of uncertainties)

Dissipated Energy (total stress analysis)



Dissipated energy per unit volume of soil (ΔW):

- Cumulative area bounded by shear stress-strain hysteresis loops
- Accounts for both amplitude and duration of earthquake ground motions

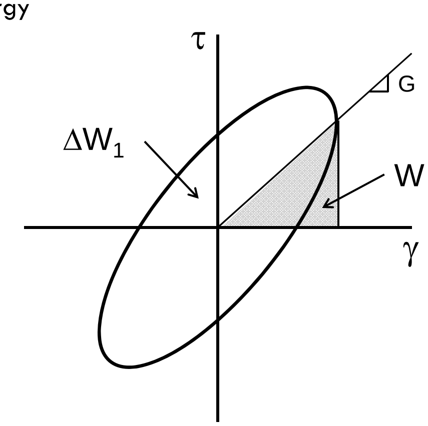
"Simplified" Approach for Determining Dissipated Energy (total stress analysis)

Relationship between Damping Ratio and Dissipated Energy

Dissipated energy in one cycle of loading

$$D = \frac{1}{4\pi}\frac{\Delta W_1}{W}$$

$$\Delta W_1 = 4\pi D W$$



“Simplified” Approach for Determining Dissipated Energy (total stress analysis)

$$W = \frac{1}{2}\tau\gamma$$

$$G = \frac{\tau}{\gamma} = G_{max}(N_{1,60cs}) \cdot \left(\frac{G}{G_{max}}\right)_{\gamma}$$

$$\Delta W_1 = \frac{2\pi \cdot D_{\gamma} \cdot \tau^2}{G_{max} \cdot \left(\frac{G}{G_{max}}\right)_{\gamma}}$$

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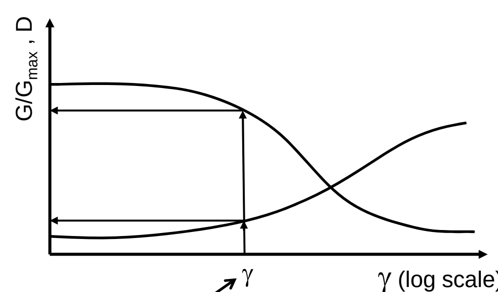

Need to iterate to determine γ

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$$\tau = 0.65 \frac{a_{max}}{g} \sigma_v r_d$$

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$$G_{max} = (v_s)^2 \cdot \rho$$

v_s can be measured or correlated to penetration resistance – if measured accounts for “aging” and increased lateral stress due to ground improvement

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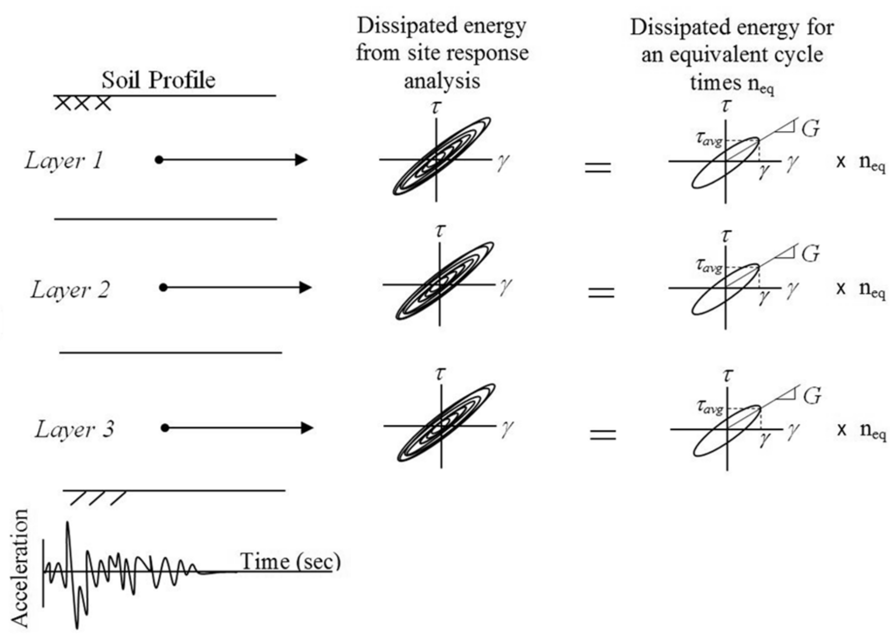
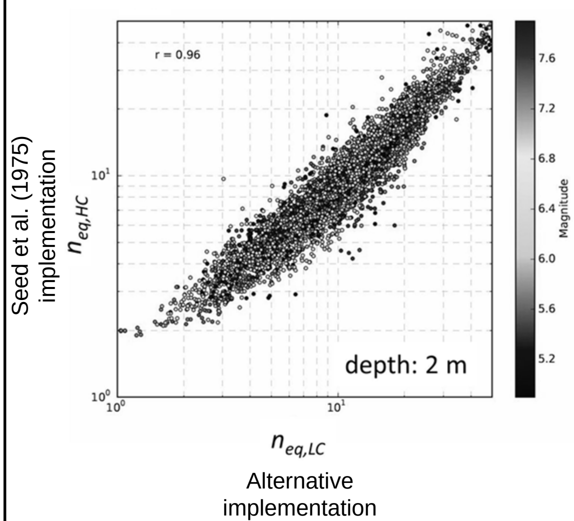
$$\Delta W_1 = \frac{2\pi \cdot D_{\gamma} \cdot \tau^2}{G_{max} \cdot \left(\frac{G}{G_{max}}\right)_{\gamma}}$$

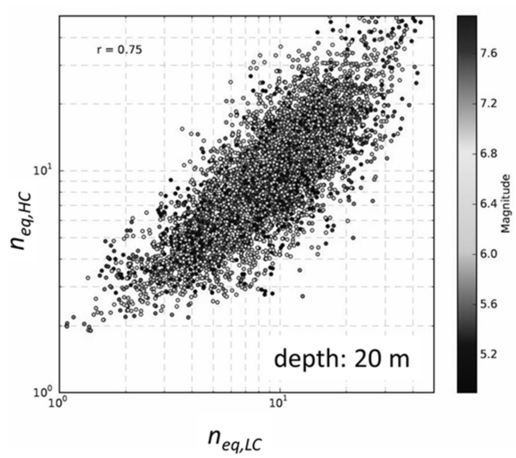
$$\Delta W = \Delta W_1 \cdot n_{eq}$$

Computation of n_{eq} Correlation

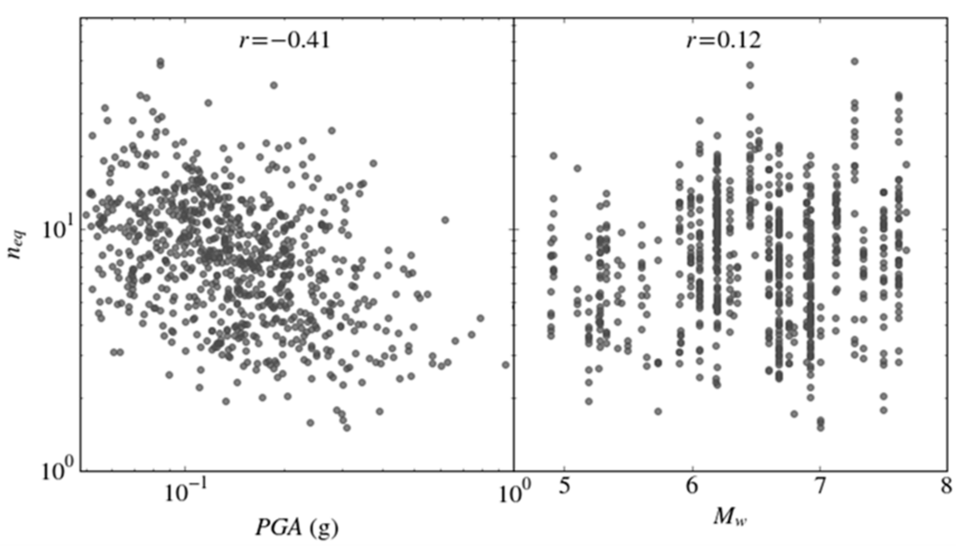


Comparison of Seed et al. (1975) and Alternative Implementation of P-M Hypothesis: n_{eq}



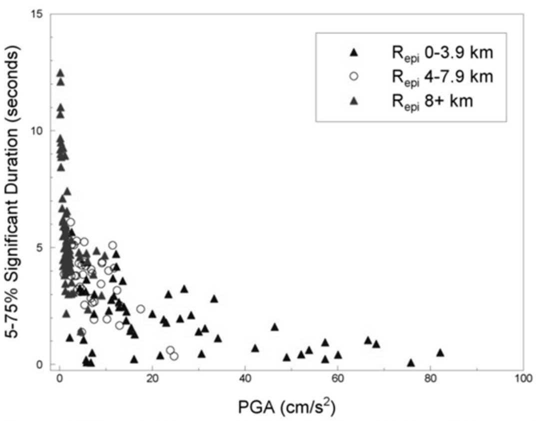


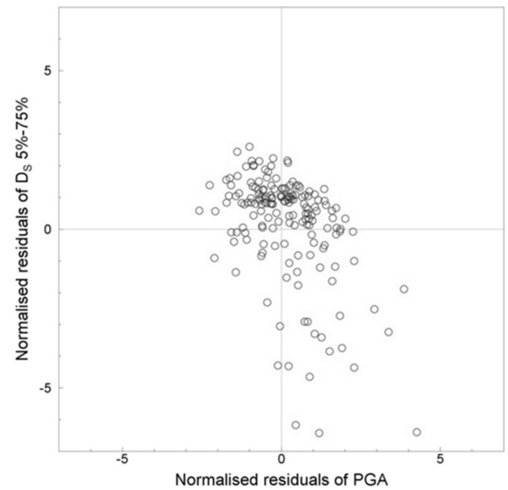
Correlation between n_{eq} and PGA



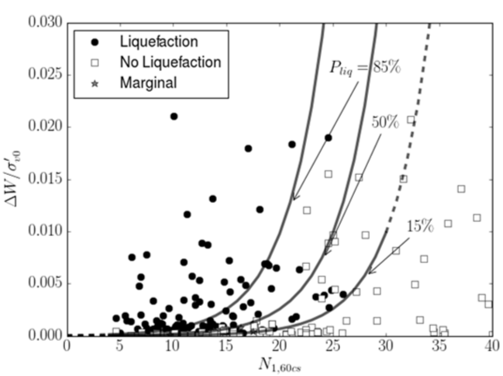
Correlation between n_{eq} and PGA

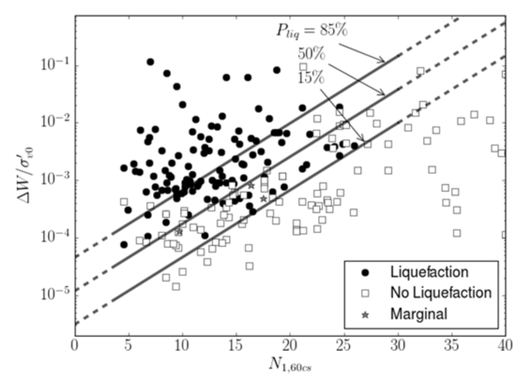
$$\ln(n_{eq}) = a_1 + a_2\ln(a_{max}) + a_3\boldsymbol{M} + \delta_{event} + \delta_{profile} + \delta_0$$





Preliminary Form of Energy-Based Charts





Relationship to Stress-Based Liquefaction Evaluation Procedure

- Parameters that can be back-calculated from energy-based procedure
  - MSF
  - K_σ
  - K_{DR}

Future Work

- Currently refining estimates of uncertainty
- Developing revised (and consistent) stress-based procedure
- Comparison for a range of earthquake scenarios with alternative procedures