Performance based Liquefaction Analysis

Evaluate Risk & Hazard consistent & efficient

1.) Different ways to handle seismic loading & uncertainty

2.) Introduce PEER Performance Based Earthquake Engineering (PBEE) framework.

Uncert: PSHA — Seismic Loading

Uncert: σ model — Soil Properties

Uncert: σ model — Site Geometry

→ Prediction Model — uncert: σ model

→ Lat Spread DSP

1. Deterministic ⟶ Scenario based (Single Scenario)
2. Pseudo - Probabilistic ⟶ Only seismic uncertainty accounted at a single Return Period.
3. Performance based (Full Probabilistic)

Intensity measure — IM → Engineering Demand Parameter — EDP → Damage Measure — DM ⟶ Decision Variable — DV

IM; magnitude, Distance, PGA, CAV

DV; cost, lives lost, safety

DM; cosmetic damage, Displacement, collapse

EDP; lateral spread displacements, settlement of building

λ = Hazard curve stuff $\frac{1}{T_r}$

$$\lambda_{DV} = \int_{IM} \int_{EDP} \int_{DM} G\langle DV|DM\rangle \, G\langle DM|EDP\rangle \, G\langle EDP|IM\rangle \, d\lambda_{IM}$$

$$G\langle \dots \rangle \rightarrow P[\,DM > dm^* \,|\, EDP\,]$$

Probability of DM exceeds dm* given EDP

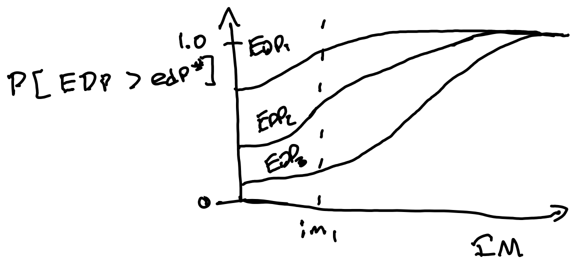
$$\lambda_{EDP} = \int_{IM} G\langle EDP|IM\rangle \, d\lambda_{IM}$$

fragility function

Hazard curve

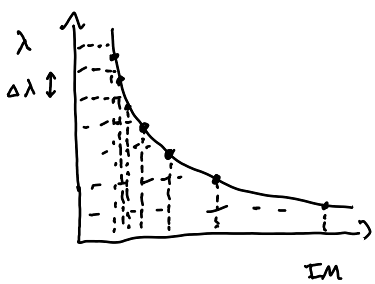
$$\lambda_{edp^*} = \sum_{i=1}^{N_{IM}} P[\,EDP > edp^* \,|\, IM_i\,] \, \Delta\lambda_{IM}$$

$edp_1 < edp_2 < edp_3$



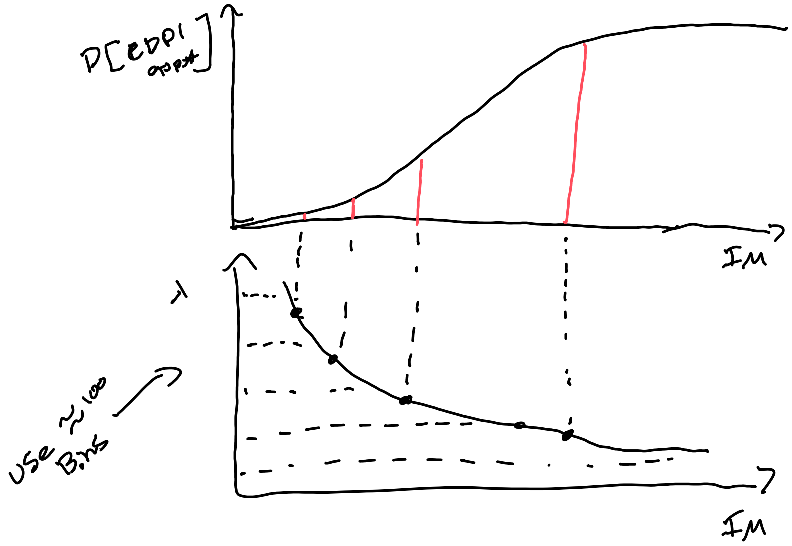
fragility curve

a family of probability

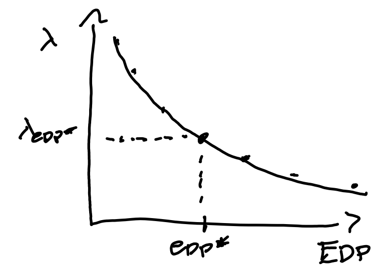


Hazard curve

Consider 1 fragility curve



$$(\,|\, + \,|\, + \,|\, + \,|\,) * \Delta\lambda_{IM} = \lambda_{edp^*}$$



Kramer & Mayfield (2007)

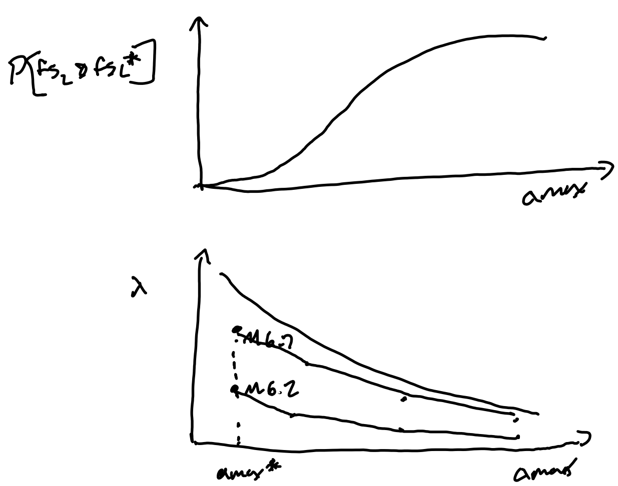
$\boxed{\text{Looking at 1 sublayer of soil}}$

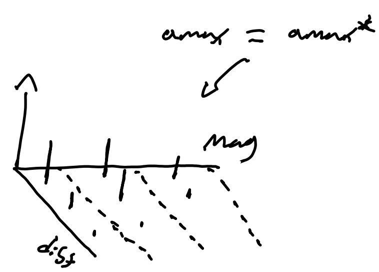
Liquefaction triggering

$$\Lambda_{FS_L^*} = \sum_{i=1}^{N_{amax}} \sum_{j=1}^{N_m} P[FS_L < FS_L^* \mid a_{max,i}, M_j] \, \Delta\lambda_{a_{max},M}$$

upper case Lambda

mean Annual rate of non exceedence





Each Point on amax Hazard curve has the Disaggregation the Disaggregation has the Percent contribution of each mag & the % cont of a mag and multiply by original λ value this gives a hazard curve of amax for each magnitude

* Repeat for every Sublayer.

Lateral Spread

Seismic Load

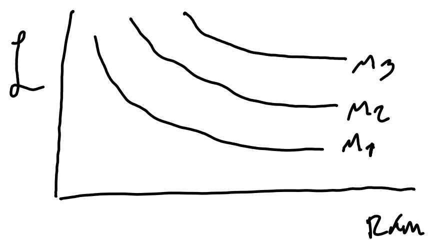
Soil Props

Site Geometry

Youd et al (2002) model

$$\text{Log}(\underbrace{D_H}_{\text{EDP}}) = \underbrace{\phi_m M + \phi_R R}_{\text{IM}} \dots \underbrace{\phi T_{15} + \phi_{15} F_{15}}_{\text{soil props}} \dots \underbrace{\phi_S S + \phi_w W(\%)}_{\text{site geometry}}$$

$$\mathcal{L} = \phi_m M + \phi_R R \dots \phi_{R^*} R^*$$



* Graphs attenuates just like PGA CAV etc.

$\mathcal{L}$ = Loading Parameter

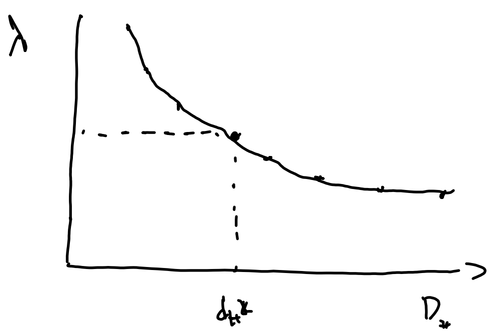
$\mathcal{S}$ = Site Parameter

$$\mathcal{S} = \left(\phi_{16} T_{15} \dots \phi_w W(\%)\right)(-1)$$

$$\text{Log}(D_H) = \mathcal{L} - \mathcal{S}$$

$$\lambda_{EDP^*} \approx \sum P\left[EDP > edp^* \mid IM_i\right] \Delta \lambda_{IM}$$

$$\lambda_{d_H^*} \quad \sum_{i=1}^{N_{\mathcal{L}}} P\left[D_H > d_H^* \mid \mathcal{L}_i \, \mathcal{S}\right] \Delta \lambda_{\mathcal{L}}$$

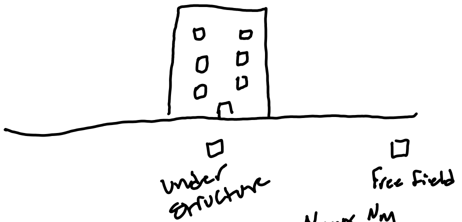


Look up → Bozorgnia CAV model

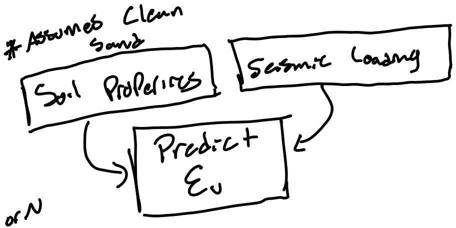
Kramer model CAV

Cambell and Bozorgnia 2010 GMPE cav equation is long and more complicated than the

Volumetric Strain



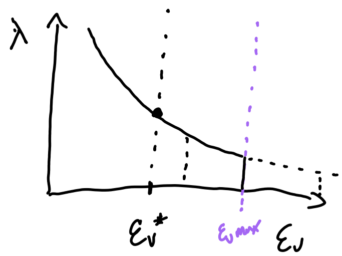
*Assumes Clean sand



$\Delta\Lambda$ Probability of non exceedance.

or N

$$\lambda_{\varepsilon_v^*} = \sum_{i=1}^{N_{FS}} \sum_{j=1}^{N_{amax}} \sum_{k=1}^{N_M} P\left[\varepsilon_v > \varepsilon_v^* \mid q_1, FS_{L_i}\right] \cdot \underbrace{P\left[FS_L < FS_{L_i} \mid amax_j, M_k\right] \Delta\lambda_{amax, M}}_{\Delta\Lambda_{FS_L}}$$

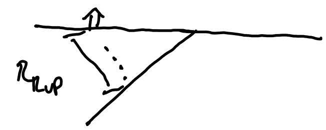


CAV

Crustal $\ln \bar{Y} = a_0 + a_1 M_w + a_2 M_w^2 + \left[(b_1 + b_2 M_w)\ln(R)\right] + b_3 R + f_1 F_R + f_2 F_N$

* What is R (Distance to Rupture)

* Assume $R = R_{Rup}$ until further knowledge



Use σ_t for uncertainty.

Bullock Settlement for Shallow Founded Structures

Soil Properties — # Hs ε [N_{160}, q_{c1N}]

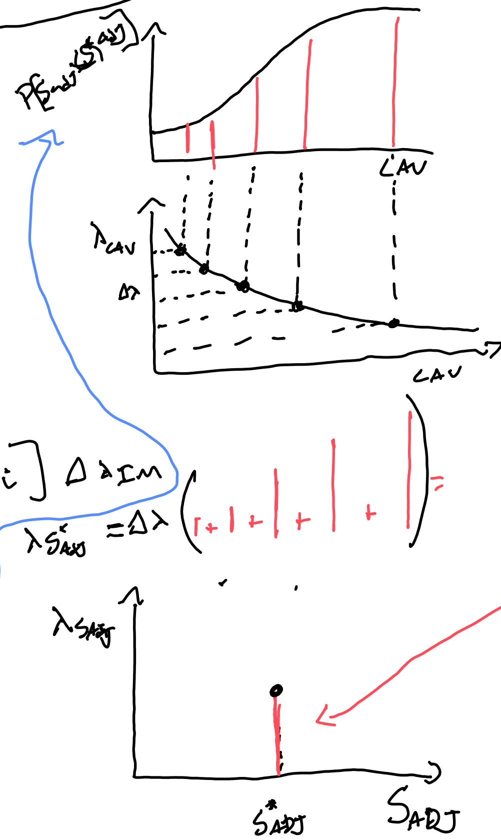
Building Props — M_{struct}, H_{eff}

Seismic Load — CAV

Foundation Props — D_f, B, L

Bullock 2017 Model

$\ln(S)_{ADJ}$



$$\lambda_{edp^*} = \sum_{i=1}^{N_{IM}} P\left[EDP > edp^* \mid IM_i\right] \Delta\lambda_{IM}$$

$$\lambda_{S^*_{ADJ}} = \Delta\lambda \left(\; + \; + \; + \; + \; \right) =$$

$$1 - \Phi\left[\frac{\ln(S_{ADJ}) - \ln(S^*_{ADJ})}{\sigma}\right]$$

☐ Auto calculate FS_{Liq}

Depth	Width	SPT N	Description	Suceptible Y/N

Depth	q_c	f_s	u

... Calculate suceptibility.