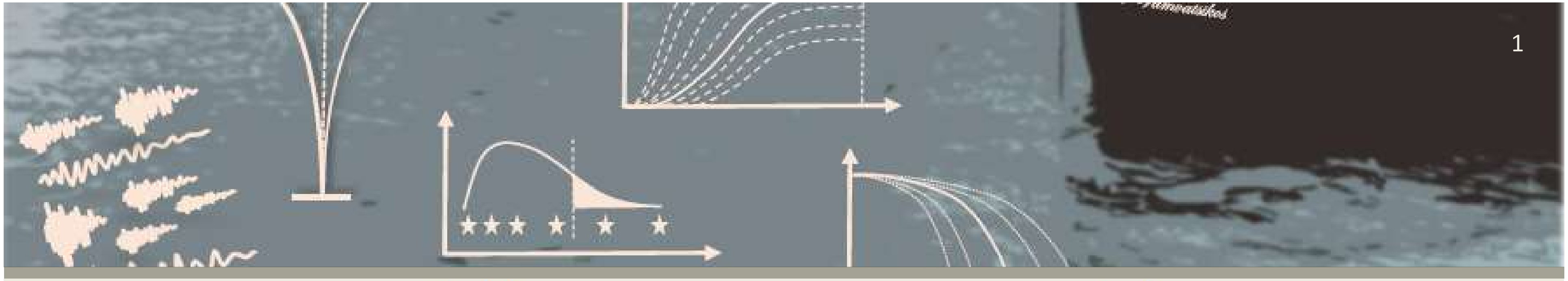
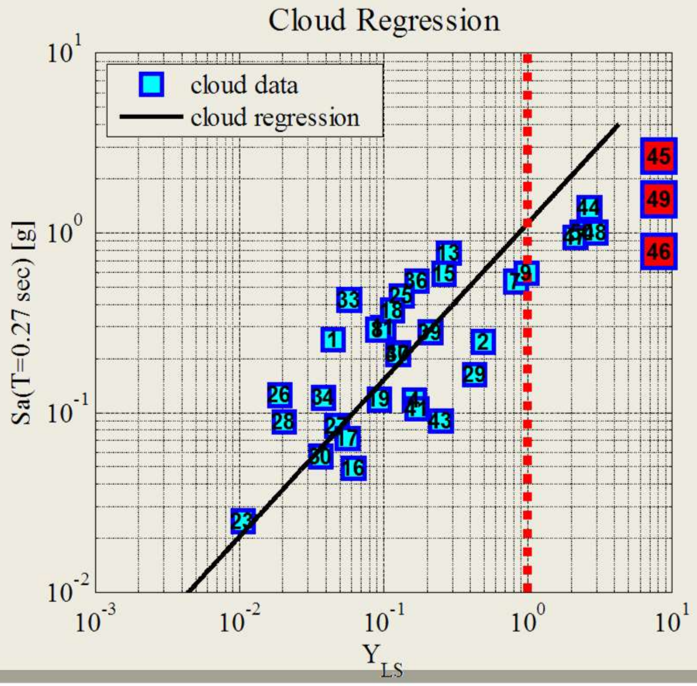
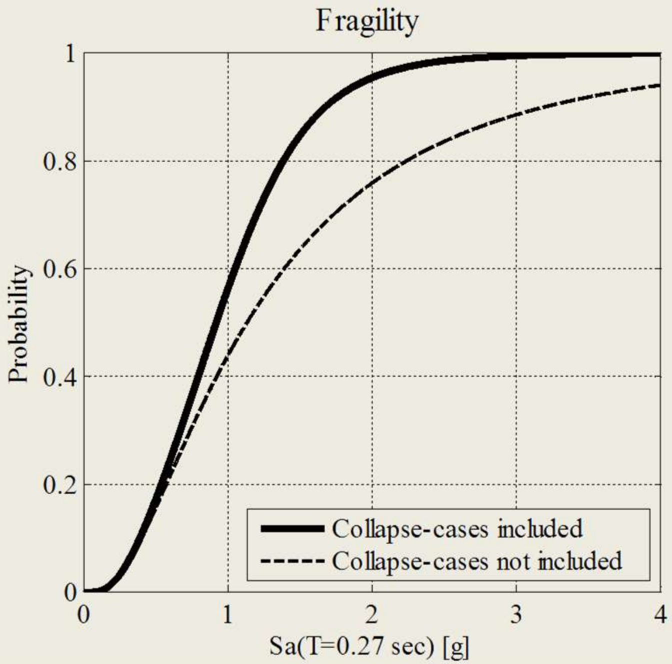






Cloud Analysis revisited again: What should we do with the "collapse" cases?

Fatemeh Jalayer, University of Naples Federico II

The 42nd Risk, Hazard & Uncertainty Workshop, Hydra, 22-25 June 2016

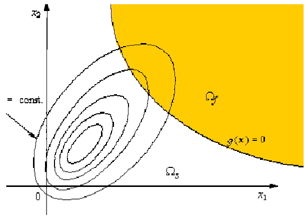
The Road Map

- Setting the scene: Y variable, Risk Integral, Fragility
- Cloud method in one slide
- The Bayesian diversion
- Considering the collpase cases
- The logistic treatment
- Achieving the softening effect on the median and the percentiles
- The [inevitable] comparison with IDA …

Performance-baced Structural Risk Assessment: The main players

$$\underbrace{\lambda_{ls}}_{\text{Risk}} = \int_{IM} \underbrace{P\left(Y_{ls} > 1 \mid IM\right)}_{\text{Fragility}} \cdot \underbrace{\left|d\lambda\left(IM\right)\right|}_{\text{Hazard}}$$

- ✓ $\lambda(IM)$ is the mean annual rate of exceeding a given IM
- ✓ $P(Y_{ls} > 1|IM)$ is the structural fragility
- ✓ λ_{ls} is the mean annual rate of exceeding a prescribed limit state

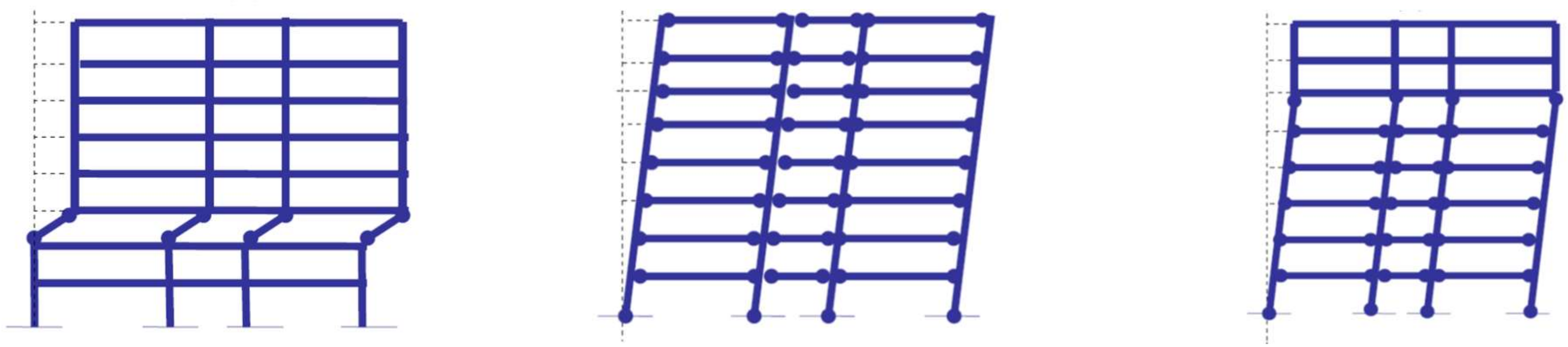


Setting the scene: The structural perfromance variable

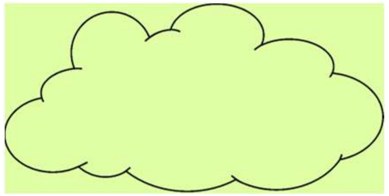
- *global mechanisms*
- Ultimate rotation
- Shear capacity
- Joint safety checking

$$Y = \overbrace{\max_{i=1,N_{mech}} \underbrace{\left(\min_{j \in I_i} \frac{D_j}{C_j} \right)}_{\text{"stronger" component}}}^{\text{"weaker" mechanism}}$$

- N_{mech} number of mechanisms
- I_i indexes of components in the i-th mechanism



Jalayer, F., Franchin, P. and Pinto, P.E., 2007. A scalar damage measure for seismic reliability analysis of RC frames. *Earthquake Engineering & Structural Dynamics*, *36*(13), pp.2059-2079.

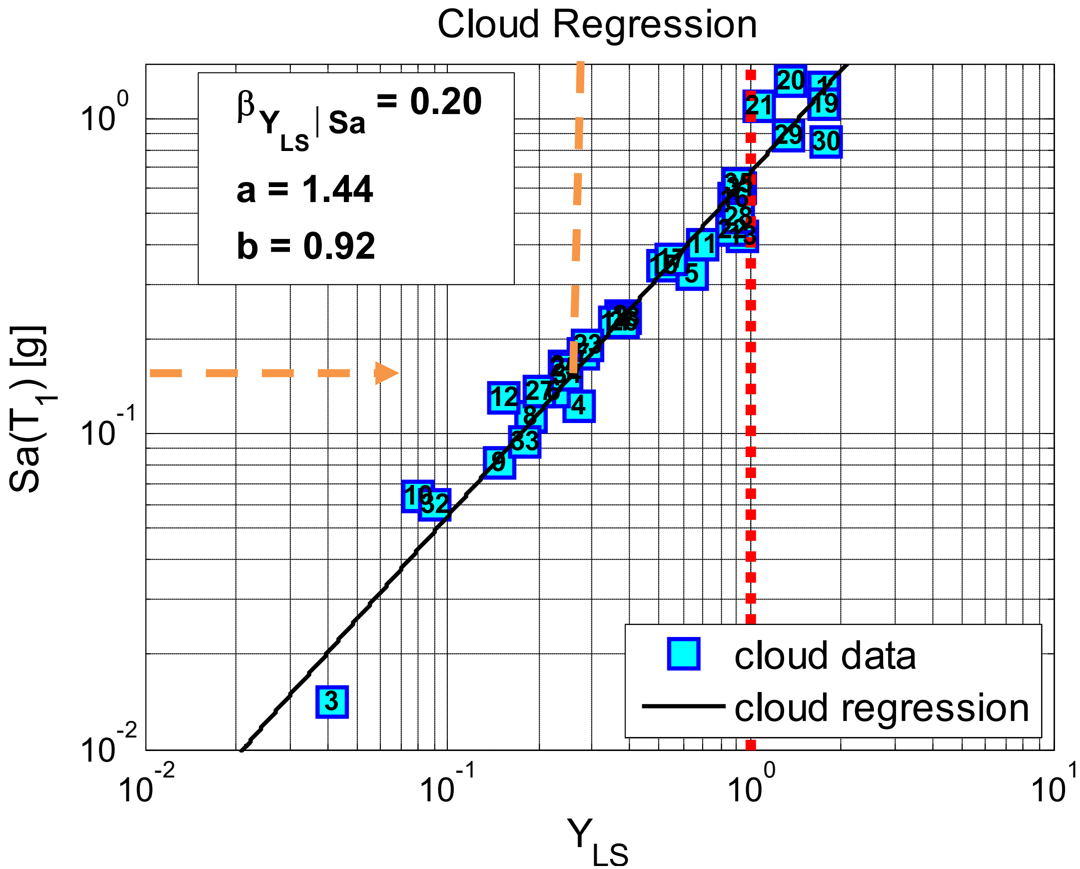


Cloud Method in One Slide

$$\log \eta_{Y|S_a} = \log a + b \log S_a$$

$$\beta_{Y|S_a} = \sigma_{\log Y|S_a} = \sqrt{\frac{\sum_{i=1}^{n} (\log Y_i - \log \eta_{Y|Sa_i})^2}{n-2}}$$

$$P(Y_{LS} > 1 \mid S_a) = \Phi\left(\frac{\log \eta_{Y|S_a}}{\beta_{Y|S_a}} \right)$$



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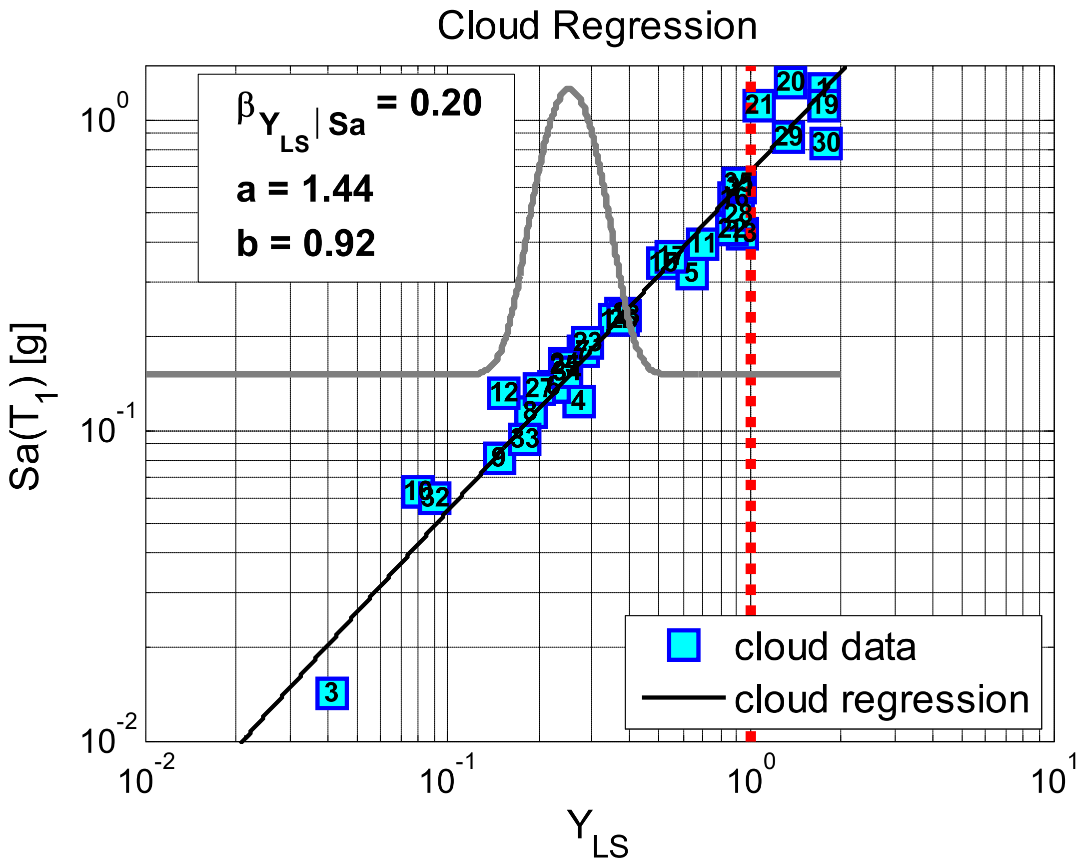
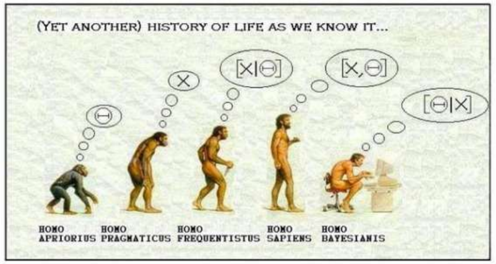




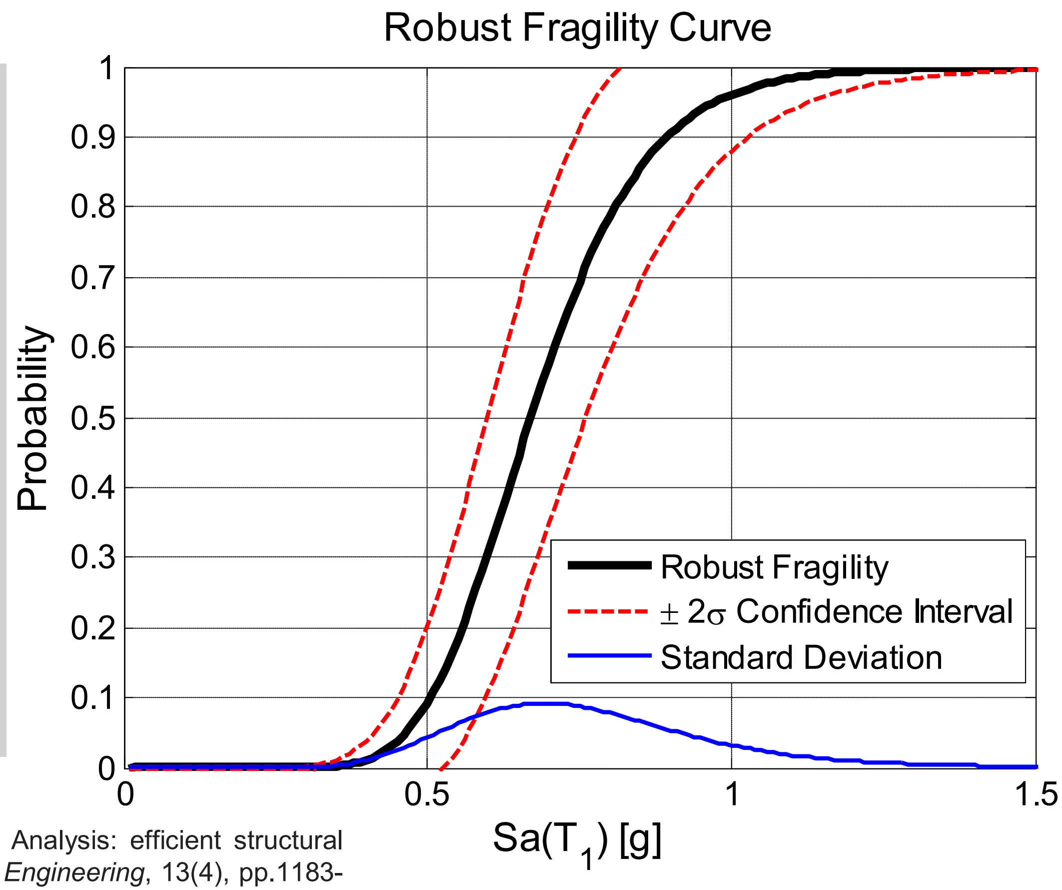
The Bayesian Take: Robust Fragility

Data Fragility Joint PDF

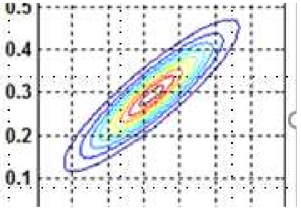
$$R(D) = \int_{\Omega(\chi)} h(\chi) \cdot p\left(\chi \middle| D\right) \cdot d\chi$$

Model Parameters

$$h(\chi) = P(Y > 1 | S_a, \chi) = \Phi\left(\frac{\log\left(\eta_{Y|S_a}\right)}{\beta_{Y|S_a}}\right)$$



Jalayer, F., De Risi, R. and Manfredi, G., 2015. Bayesian Cloud Analysis: efficient structural fragility assessment using linear regression. *Bulletin of Earthquake Engineering*, 13(4), pp.1183-1203.



The posterior distribution for χ

Bi-variate Normal Distribution

$$p(\chi \mid \boldsymbol{D}) = p(\log a, b, \beta_{Y|IM} \mid \boldsymbol{D}) = \underline{p(\log a, b \mid \beta_{Y|IM}, \boldsymbol{D})} \cdot \underline{p(\beta_{Y|IM} \mid \boldsymbol{D})}$$

Chi-Square Distribution

- ✓ χ=[log a, b, $\beta_{Y|IM}$] is the vector of the parameters (regression coefficients and standard deviation) for the prescribed Log-Normal fragility function.
- ✓ Where $p(\beta_{Y|IM}|\boldsymbol{D})$ is the marginal posterior distribution of $\beta_{Y|IM}$
- ✓ Where $p(\log(a), b \mid \beta_{Y|IM}, \boldsymbol{D})$ is the conditional posterior distribution of log(a),b given β

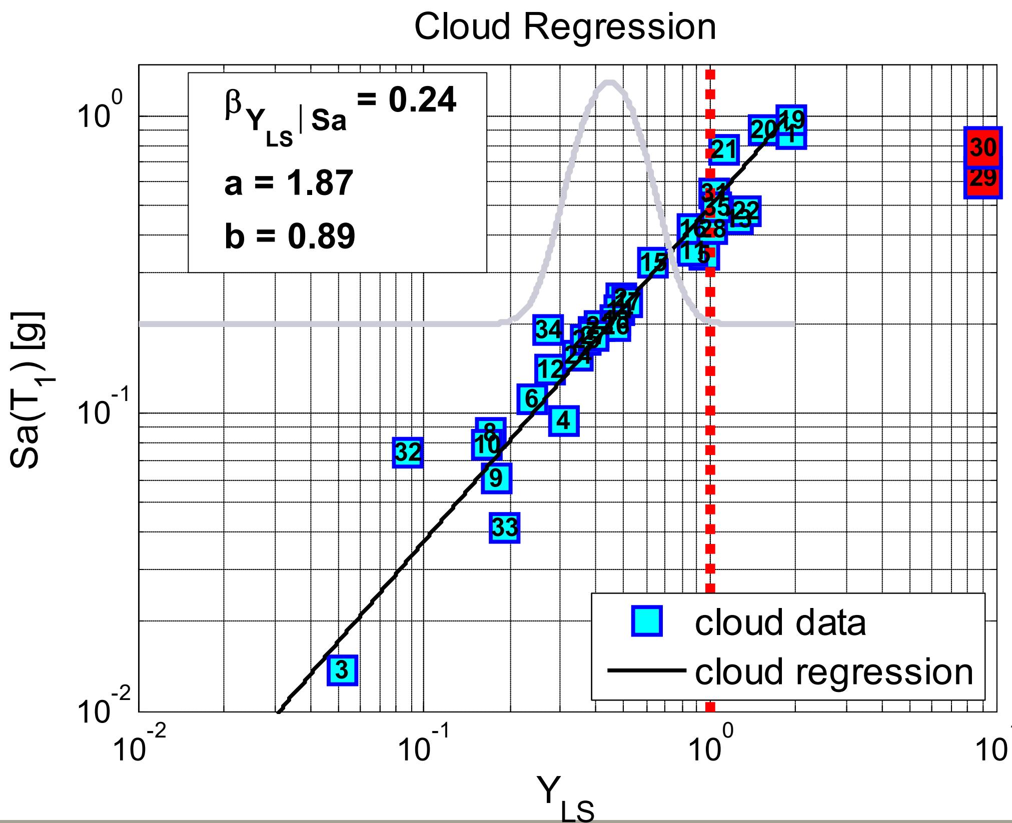
Taking into account the collapse cases

$$P(Y_{LS}>1\,|\,S_a)=P(Y_{LS}>1\,|\,S_a,NC)P(NC\,|\,S_a)+P(Y_{LS}>1\,|\,S_a,C)P(C\,|\,S_a)$$

$$\log\eta_{Y|NC,S_a}=\log a+b\log S_a$$

$$\beta_{Y|IM}=\sigma_{\log Y|NC,S_a}=\sqrt{\frac{\sum_{i=1}^{n}(\log Y_i-\log\eta_{Y|NC,S_{a,i}})^2}{n-2}}$$

$$P(Y_{LS}>1\,|\,S_a,NC)=\Phi\left(\frac{\log\eta_{Y|NC,S_a}}{\beta_{Y|NC,S_a}}\right)$$



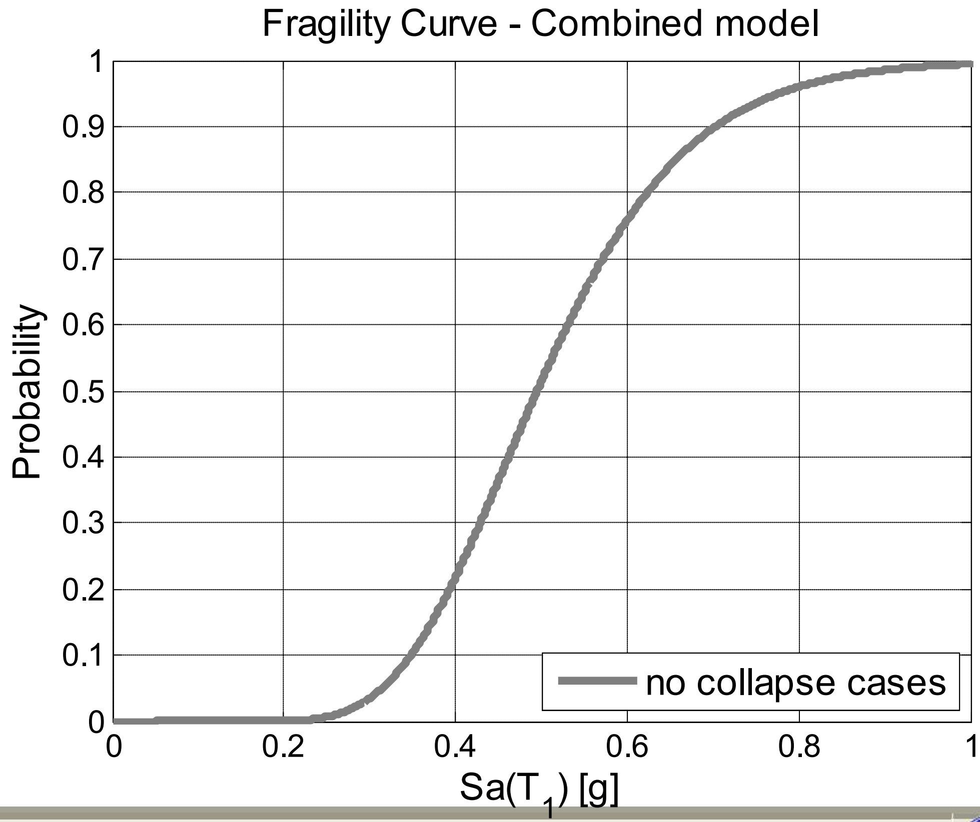
Taking into account the collapse cases

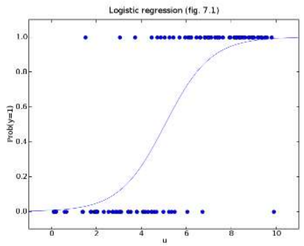
$$P(Y_{LS}>1|S_a)=P(Y_{LS}>1|S_a,NC)P(NC|S_a)+P(Y_{LS}>1|S_a,C)P(C|S_a)$$

$$\log\eta_{Y|NC,S_a}=\log a+b\log S_a$$

$$\beta_{Y|IM}=\sigma_{\log Y|NC,S_a}=\sqrt{\frac{\sum_{i=1}^{n}(\log Y_i-\log\eta_{Y|NC,S_{a,i}})^2}{n-2}}$$

$$P(Y_{LS}>1|S_a,NC)=\Phi\left(\frac{\log\eta_{Y|NC,S_a}}{\beta_{Y|NC,S_a}}\right)$$



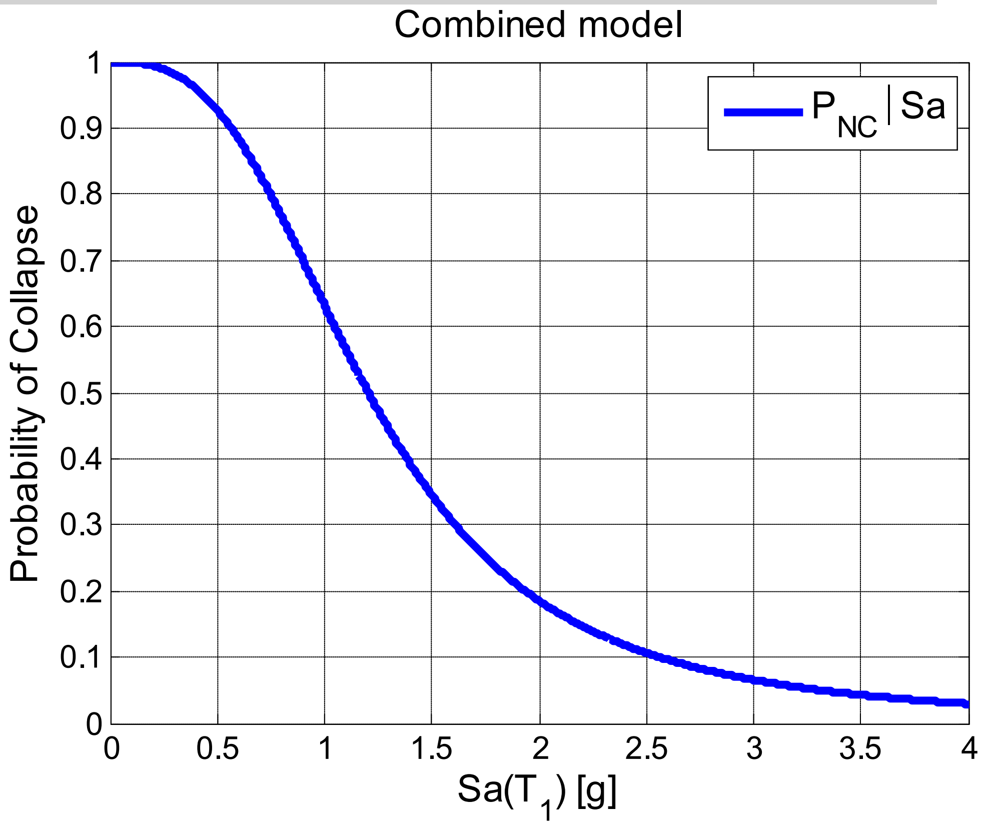


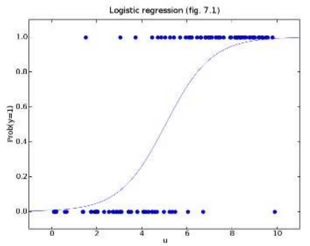
Taking into account the collapse cases:

The logistic regression

$$P(Y_{LS} > 1 \mid S_a) = P(Y_{LS} > 1 \mid S_a, NC)P(NC \mid S_a) + (1 - P(NC \mid S_a))$$

$$P(NC \mid IM) = \frac{\mathrm{e}^{-(\beta_o + \beta_1 \cdot S_a)}}{1 + \mathrm{e}^{-(\beta_o + \beta_1 \cdot S_a)}}$$



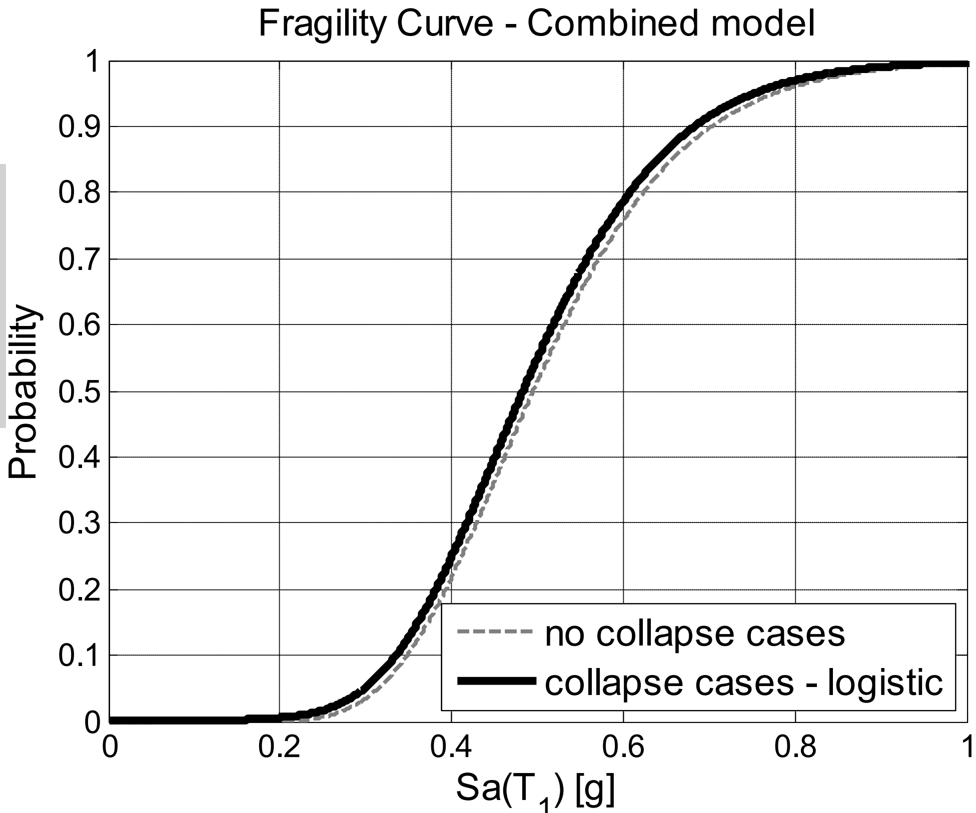


Taking into account the collapse cases:

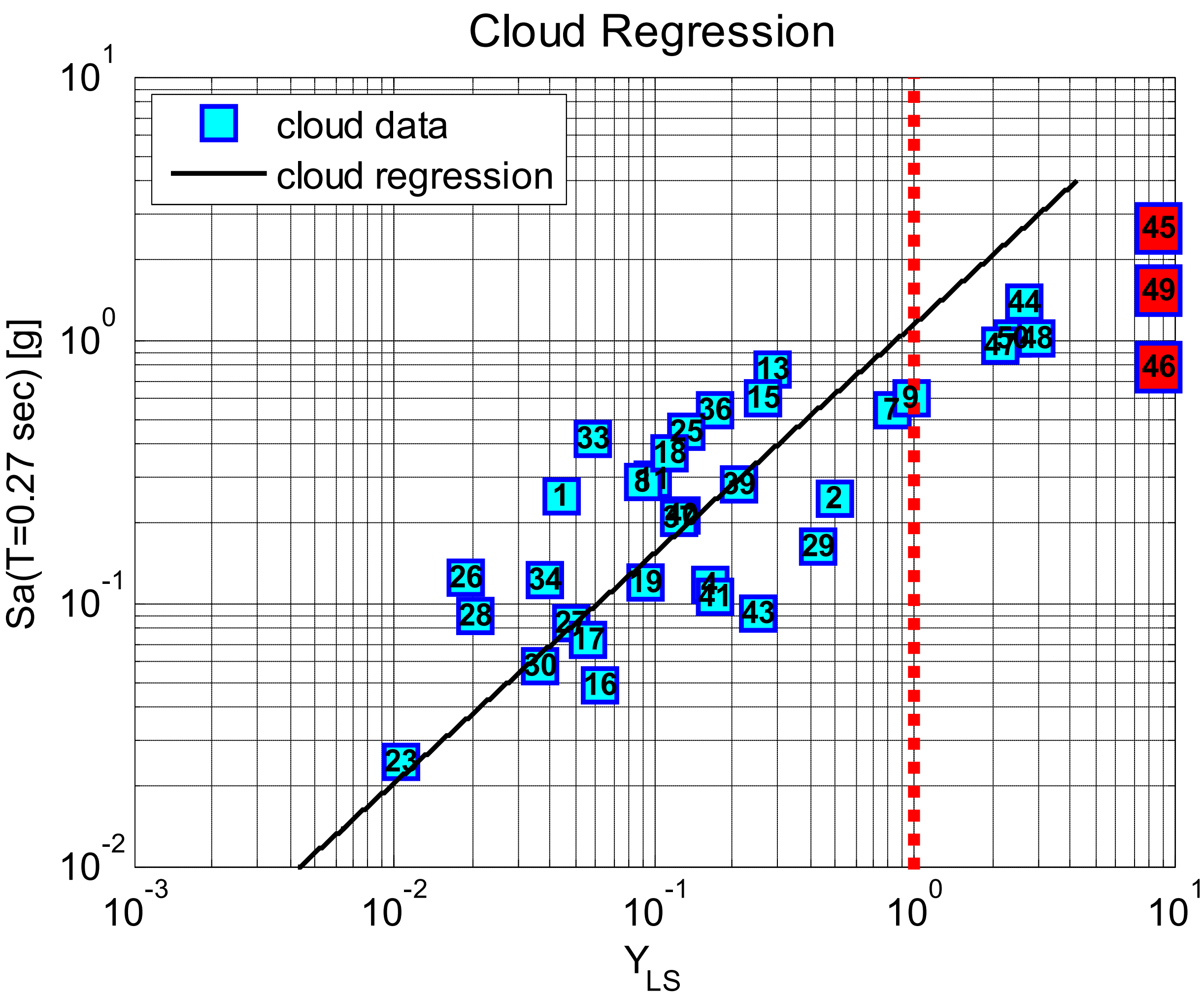
The logistic regression

$$P(Y_{LS} > 1 \mid S_a) = P(Y_{LS} > 1 \mid S_a, NC)P(NC \mid S_a) + (1 - P(NC \mid S_a))$$

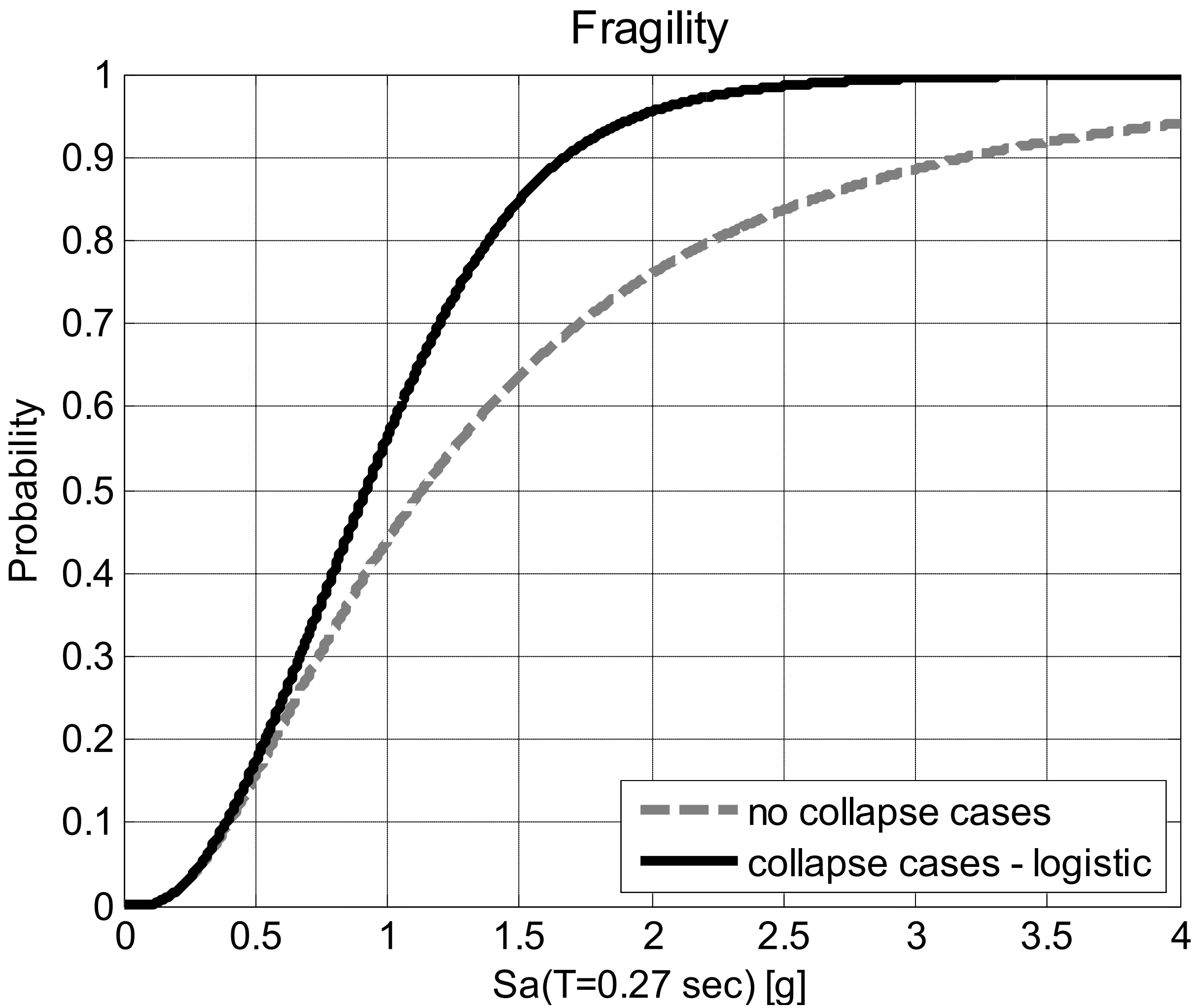
$$P(NC \mid IM) = \frac{\mathrm{e}^{-(\beta_o + \beta_1 \cdot S_a)}}{1 + \mathrm{e}^{-(\beta_o + \beta_1 \cdot S_a)}}$$



Taking into account the collapse cases: Another example

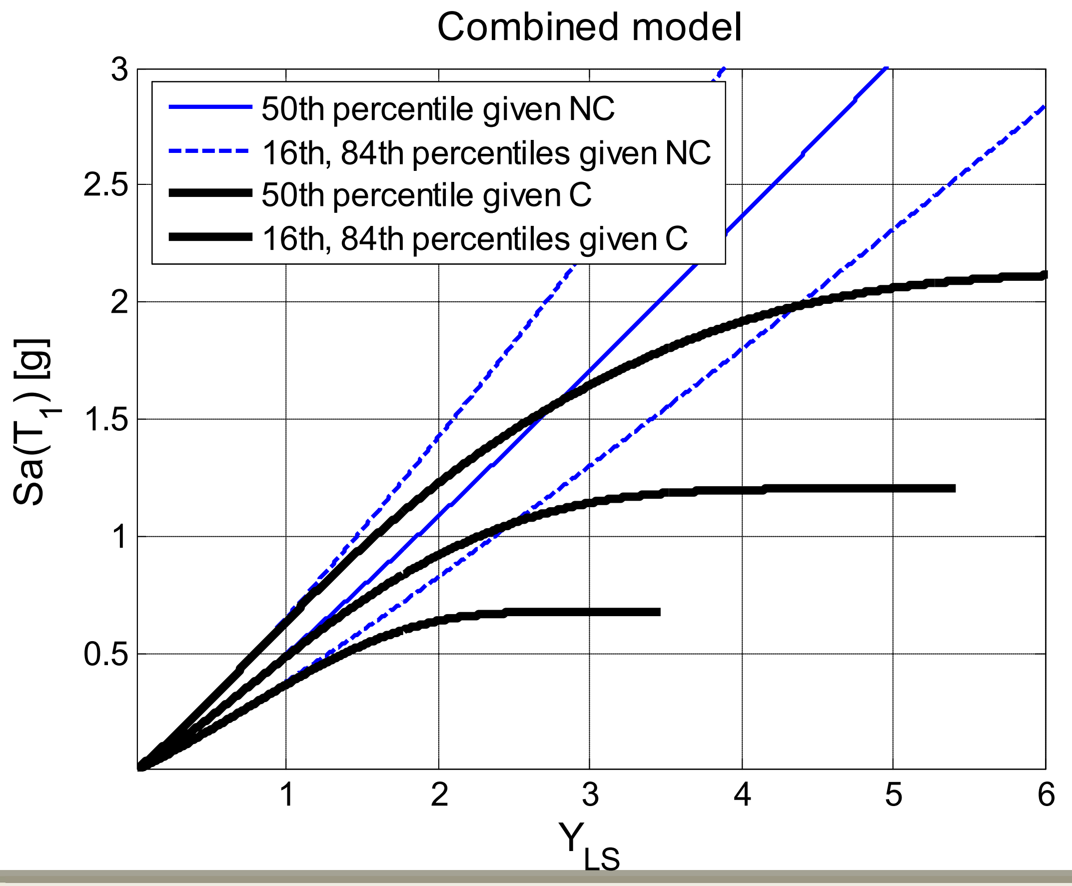


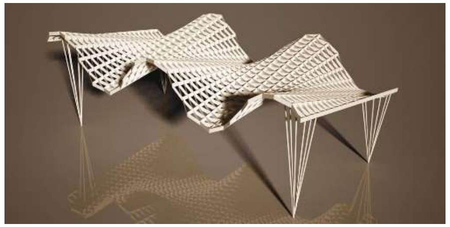
Taking into account the collapse cases: Another example



Taking into account the collapse cases: The percentiles

$$y^{p} = \eta_{Y|IM,NC} \cdot \exp(\beta \cdot \Phi^{-1}\left(\frac{p}{P(NC|S_a)}\right))$$

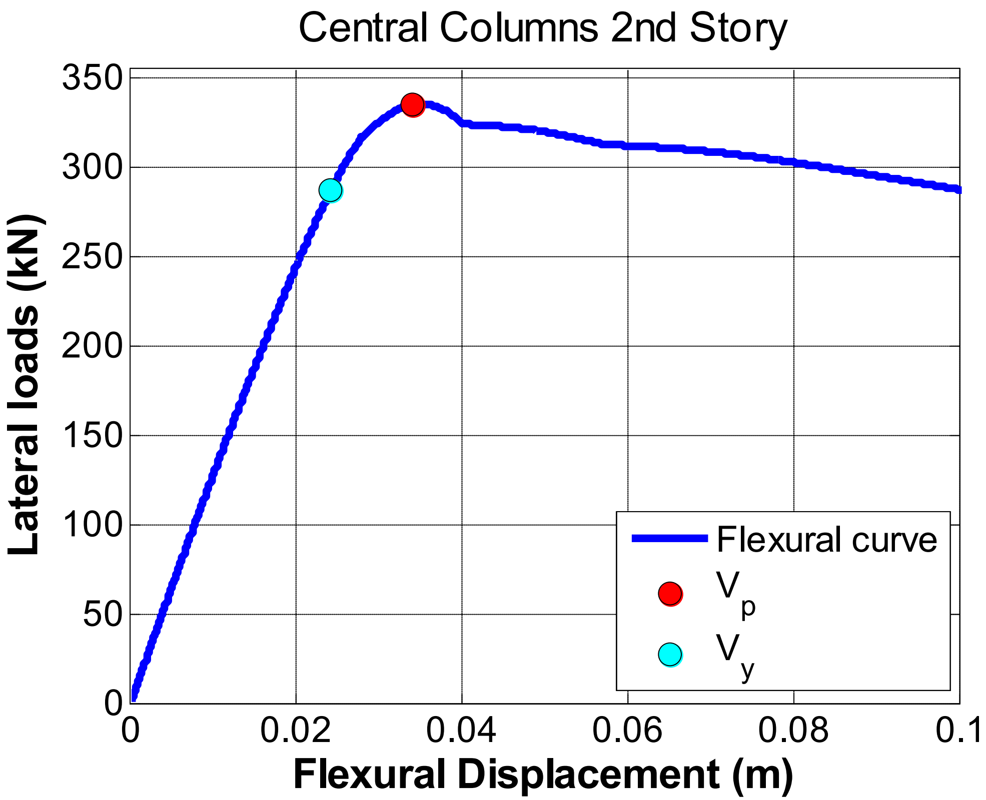


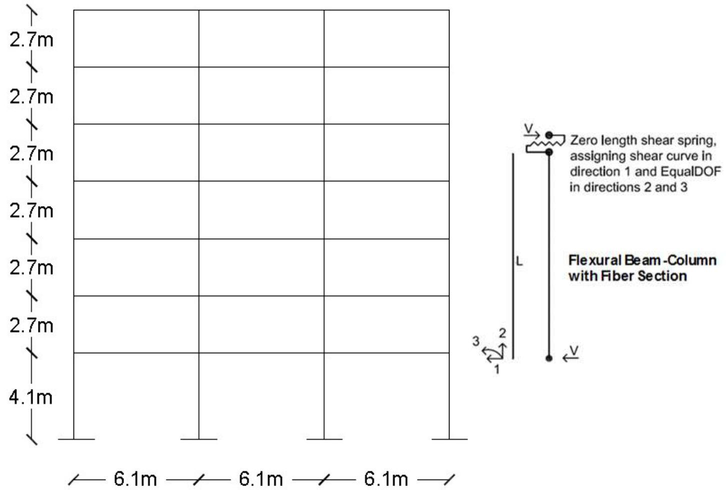


The Structural Model:

Van Nuys Hotel Transeversal Frame

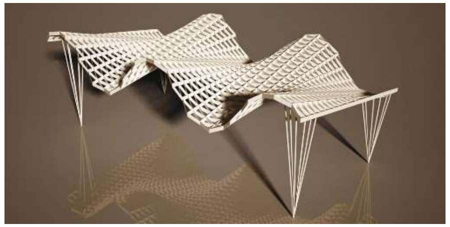
✓ The structutre has been re-modelled using OPENSEES and considering the axial-shear-flexural interaction





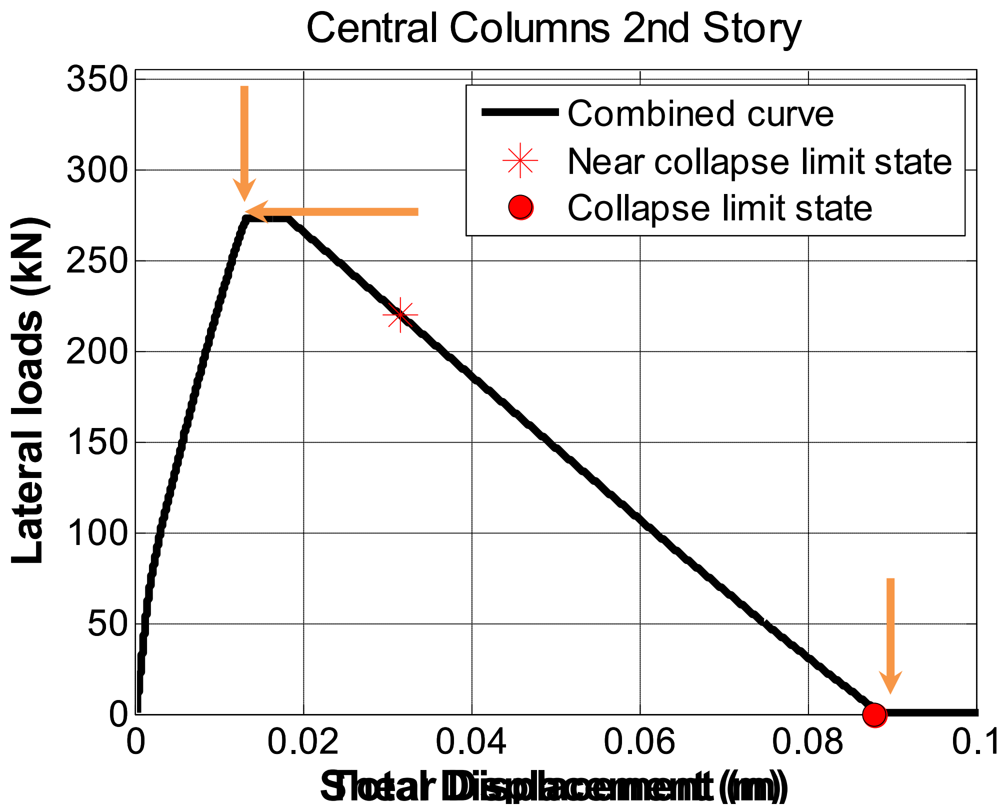
✓ The concrete 01 material has been used for modelling the concrete behavior.

✓ The longitudinal bars are modeled using the Steel02 with 1% strain hardening.



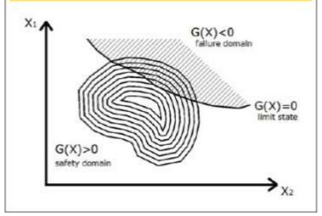
The Structural Model:

Van Nuys Hotel Transversal Frame



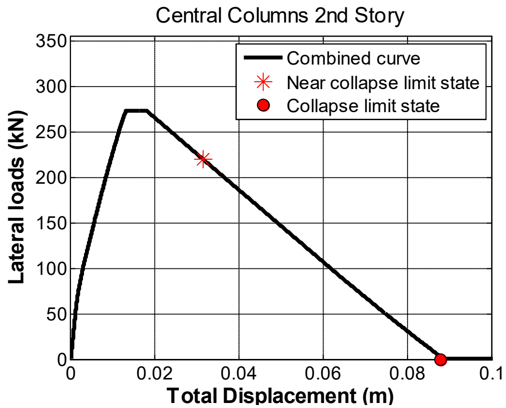
- ✓ The shear strength is modeled using Sezen and Moehle 2004.
- ✓ The shear drift at shear failure is calculated from Gerin and Adebar 2004.
- ✓ The drift at axial failure is calculated from Elwood and Moehle 2003.

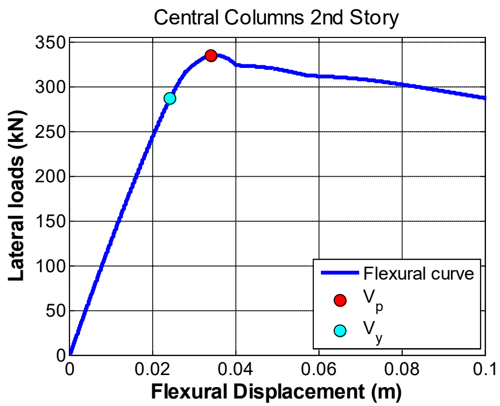
Figure 5 – Failure and safety domains considering two random variables

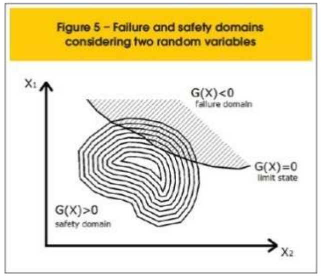


The Limit State of Near Collapse

Failure Type	Component(s)	Definition / Description
Ductile/Brittle	column / beam	$\theta_{max}>\theta_{ultimate}$
Soft-story mechanism	all columns of one story	$\theta_{max}>\theta_{yielding\text{-}flexure}$
Partial mechanism	for a number of adjacent stories: all beams + bottom and top columns	$\theta_{max}>\theta_{yielding\text{-}flexure}$
Global mechanism	for the entire building: all beams + base columns	$\theta_{max}>\theta_{yielding\text{-}flexure}$

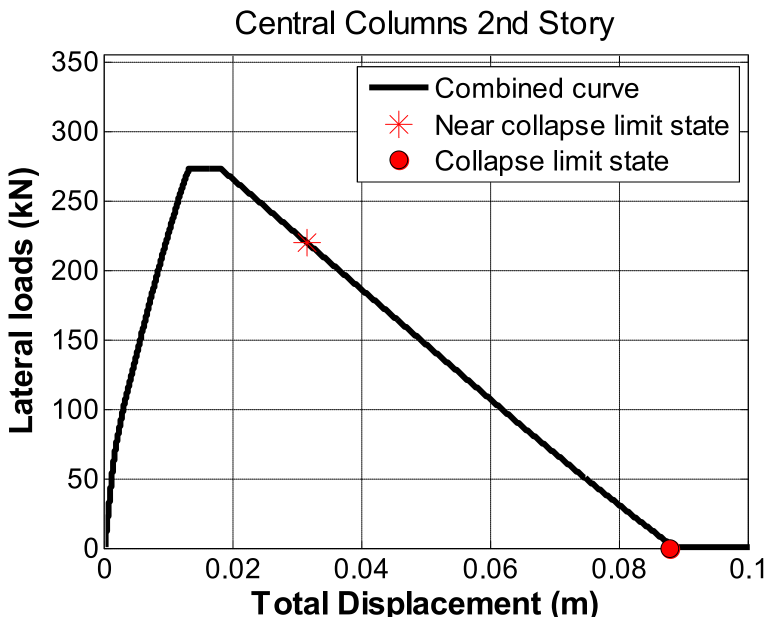






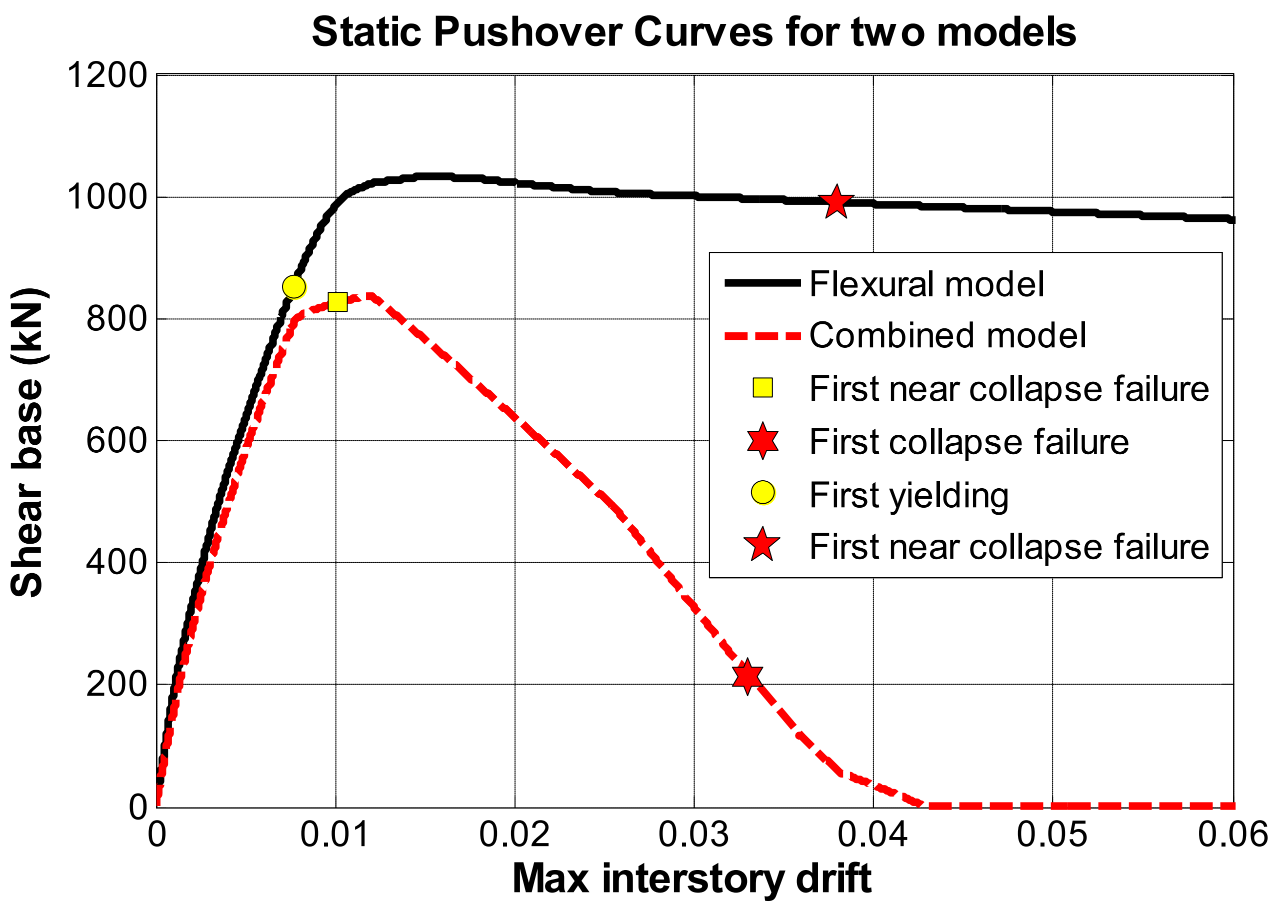
The Limit State of Collapse

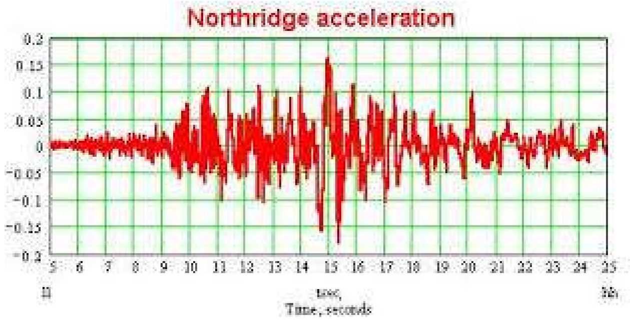
Collapse Type	Component(s)	Definition / Description
Ductile	50% +1 of the columns of one story	$\theta_{max} > \theta_{ultimate}$
Brittle	50% +1 of the columns of one story	$\theta_{max} > \theta_{axial}$



Galanis, P.H. and Moehle, J.P., 2012. Development of collapse indicators for older-type reinforced concrete buildings. In Proceedings of the 15th World Conference on Earthquake Engineering (WCEE).

The static pushover curve

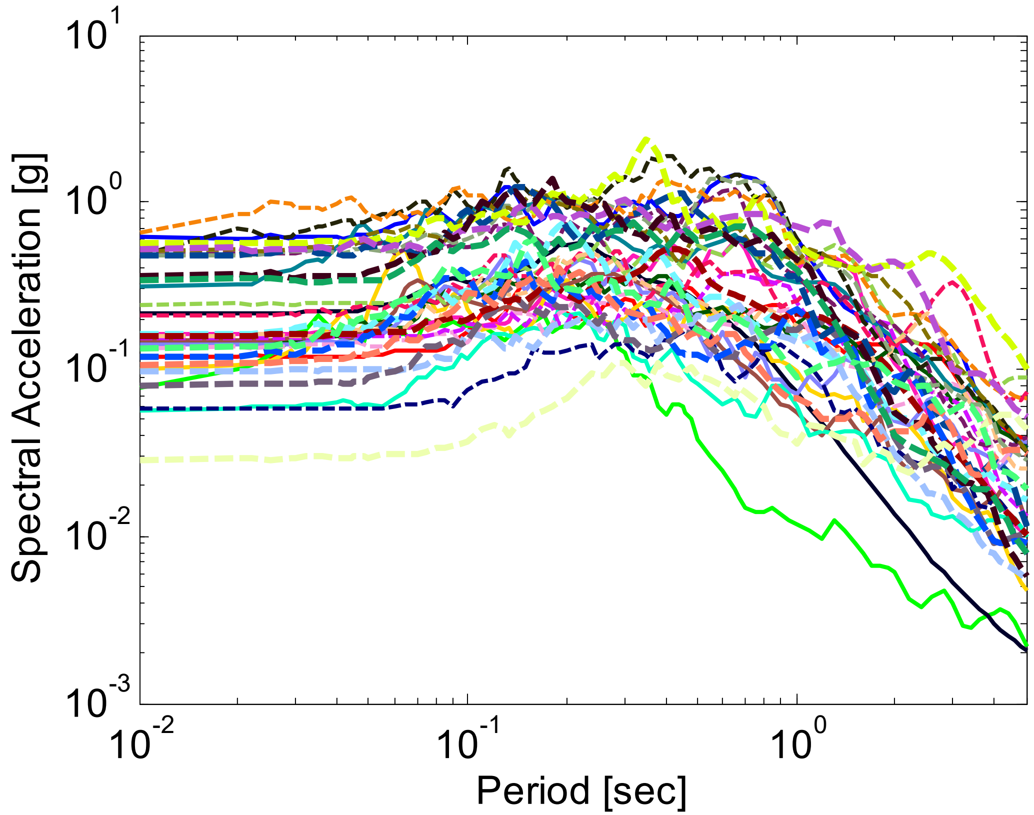




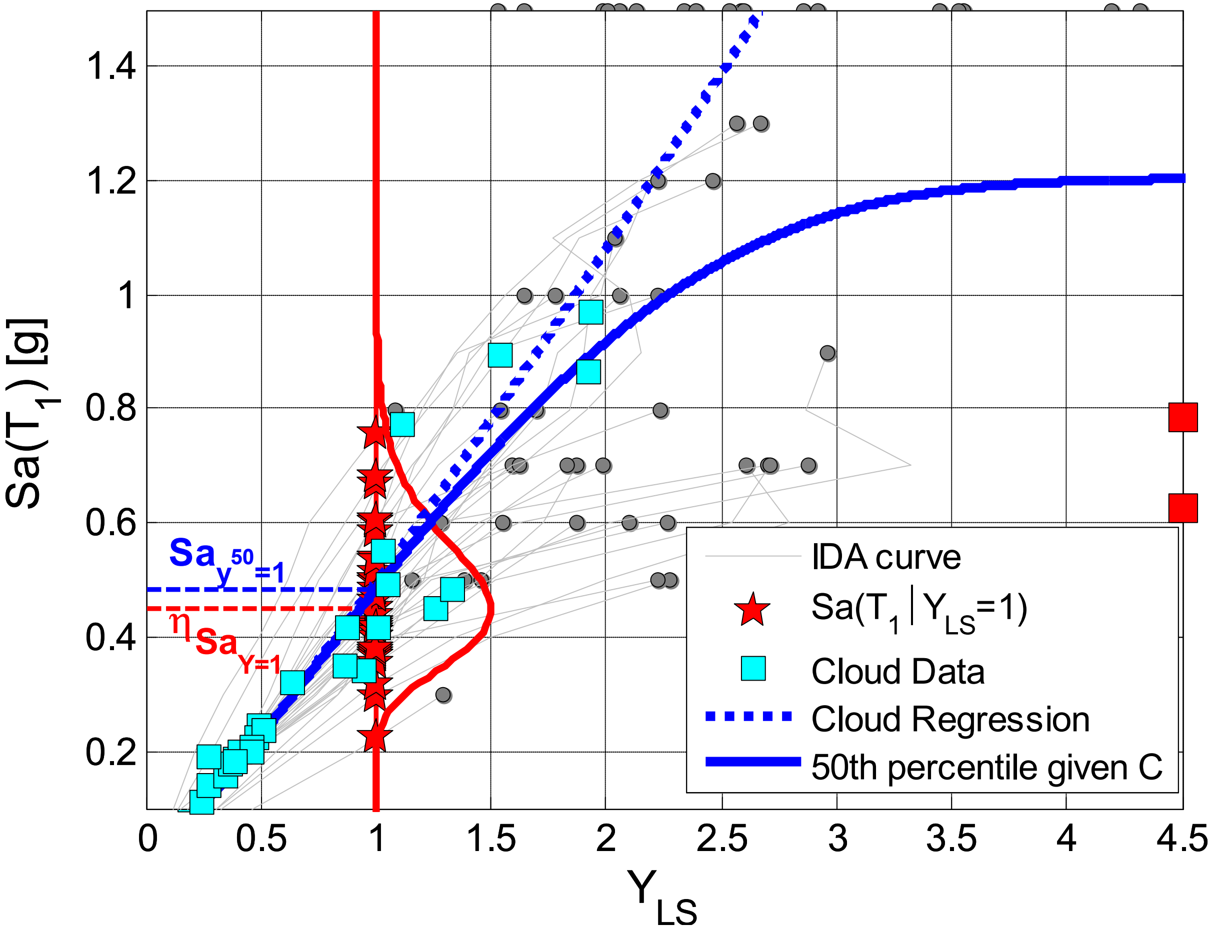
Record Selection

- ✓ A set of 35 records for the California sites.
- ✓ Stiff soil (Geo Matrix types Cand D)
- ✓ Moment magnitude and Joyner-Boor distance in the range:

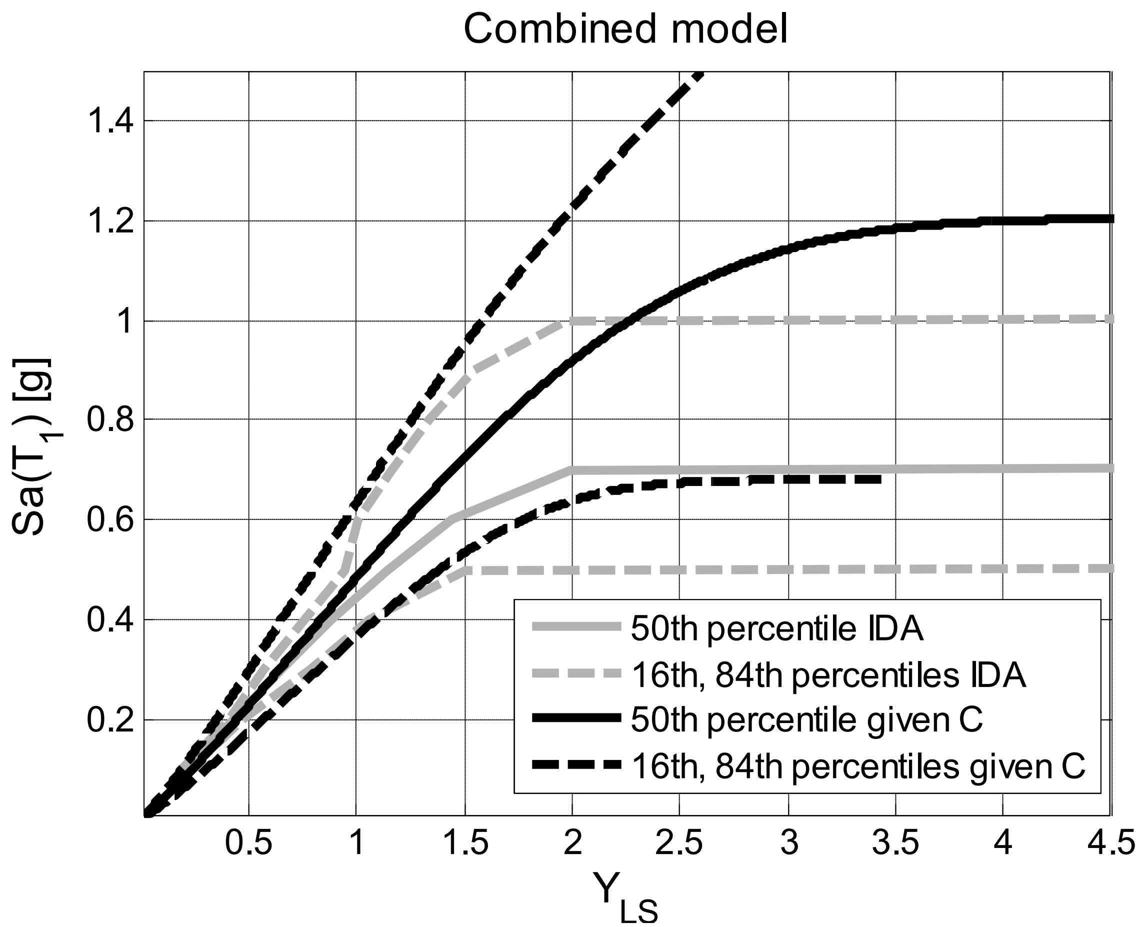
5.0 < M < 7.5   0.1 < R < 115 km

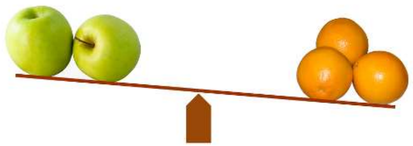


Comparison CLOUD - IDA

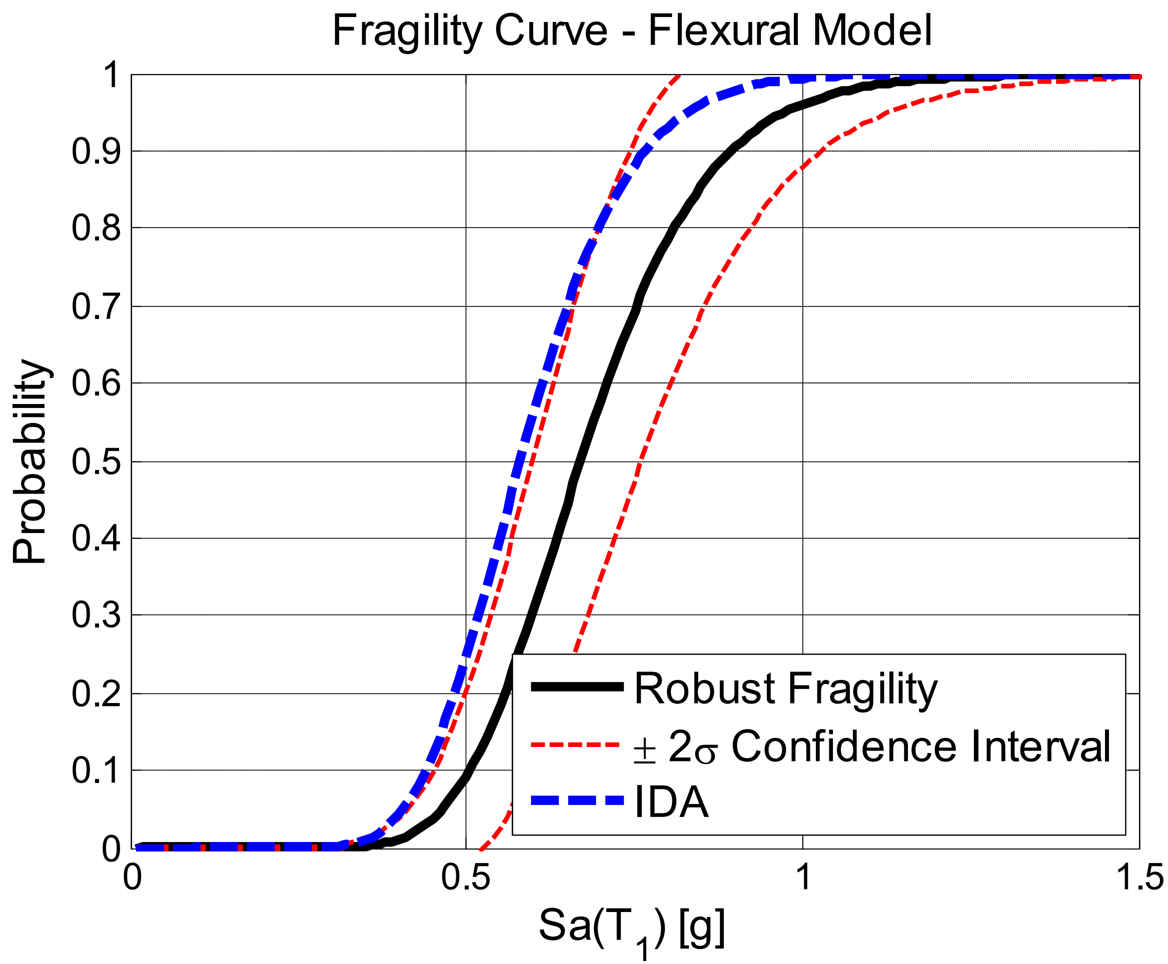


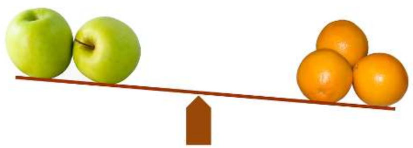
The percentiles, comparison with IDA



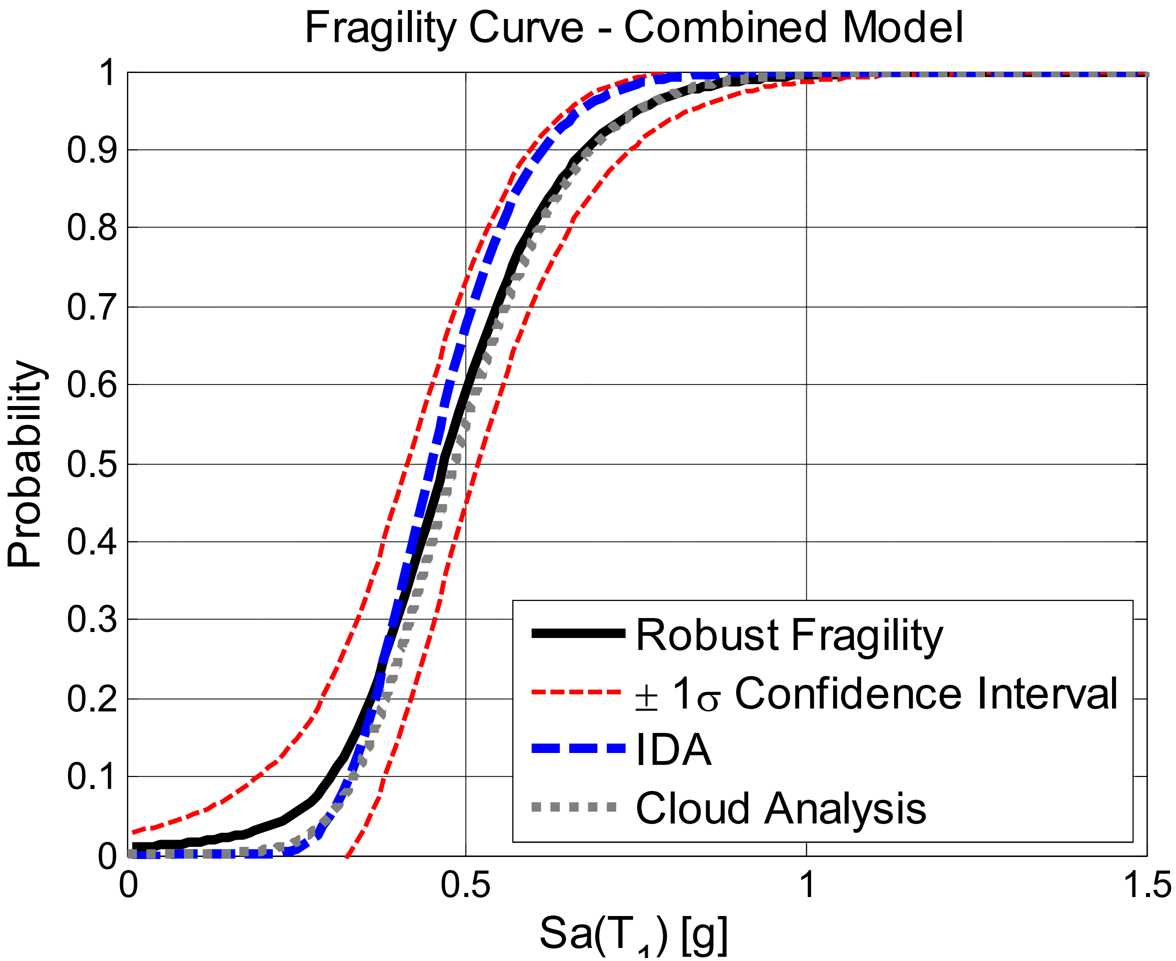


The fragilities, comparison with IDA





The fragilities, comparison with IDA



Some final thoughts

- ✓ Mixing a simple logarithmic regression model and a logistic regression model permits a systematic handling of the collapse cases;
- ✓ Using the cloud with performance-based variable defined based on cut-sets can overcome the need for identifying the collapse cases by setting rather arbitrary thresholds;
- ✓ The cloud method if coupled with careful record selection can lead to reasonable results (in comparison with IDA);
- ✓ This also helps in achieving the famous softening effect in the percentiles of EDP given IM;
- ✓ The bayesian robust fragility estimate helps in defining a confidence interval taking into account the uncertainty in the parameters of the fragility curve;
- ✓ The robust fragility can be calculated also in the case considering the collapses;

Thank You

Special Thanks to:

Dr. Hossein Ebrahimian
Post-doctoral Researcher
University of Naples Federico II

and

Andrea Miano
Ph.D. Candidate
University of Naples Federico II