2019 PEER Annual Meeting Poster Session

Uncertainty Propagation in the Seismic Collapse Risk for Single-Family Wood-frame Residences

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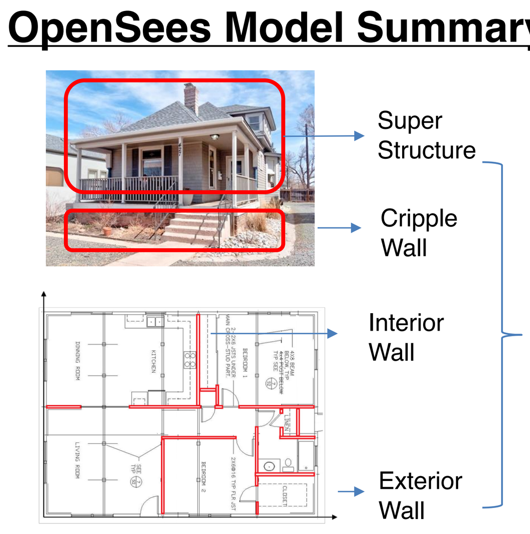
1. Motivation & Introduction

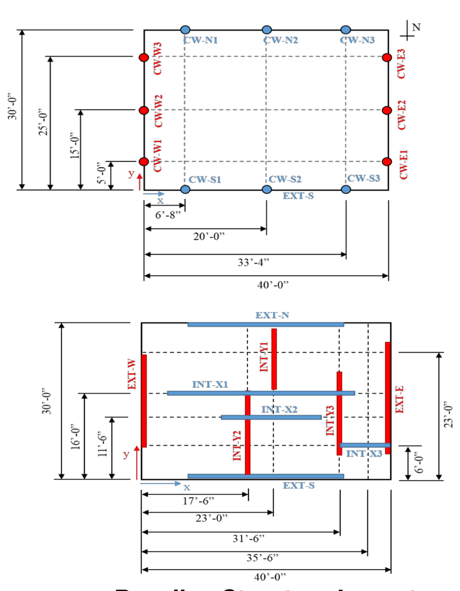
- Buildings constructed with adjacent stories having large differences in strength and stiffness can lead to the formation of a single-story mechanism during earthquake shaking. This type of behavior is undesirable because inelastic deformation is concentrated in a few non-ductile components of a single story instead of being distributed along the height of the building, which can lead to sideway collapse.
- Policy actions are often implemented to mitigate the effects soft-story vulnerabilities. A major challenge with developing such guidelines is being able to adequately capture the variations in structural configurations and material properties of the affected structures. Furthermore, multiple sources of uncertainties (i.e. structure dimensions, construction quality) must be addressed when developing retrofit techniques than can be generalized for a given portfolio. Furthermore, the tools, methods and guidelines that are currently available primarily designing retrofits to provide adequate strength and inelastic deformation capacities. However, within the framework of performance-based seismic design (PBSD) (Moehle & Deierlein, 2004), little or no consideration is given to earthquake-induced economic losses.

2. Building Prototype and Sample Analysis

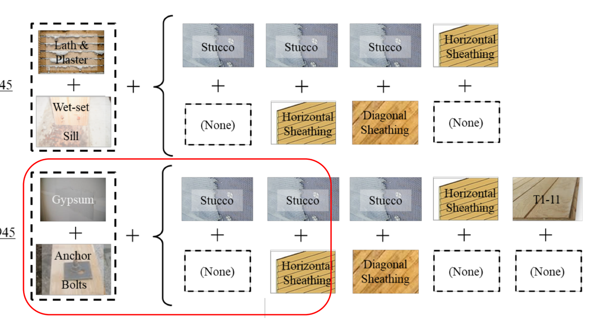
- **OpenSees Model Summary**



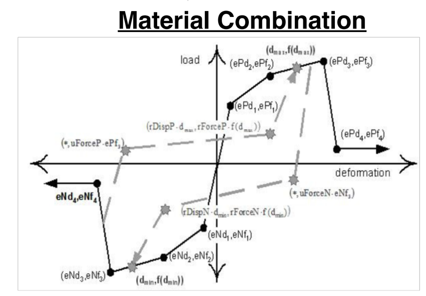
Single Family House with Cripple Wall



Baseline Structure Layout

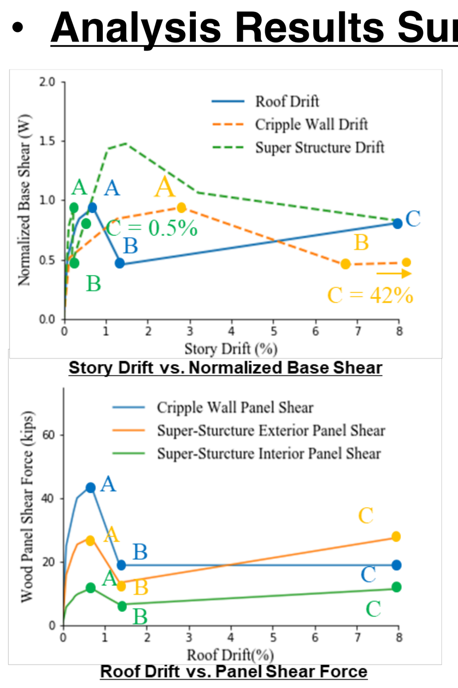


Material Combination



Pinching4 Material Model

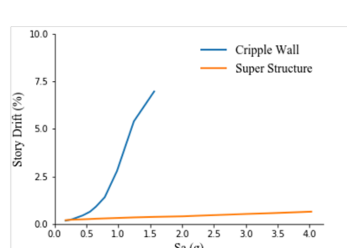
- **Analysis Results Summary**



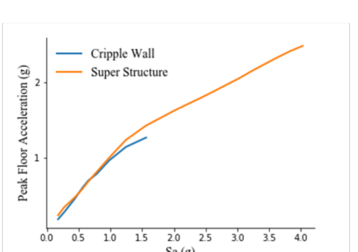
Story Drift vs. Normalized Base Shear

Roof Drift vs. Panel Shear Force

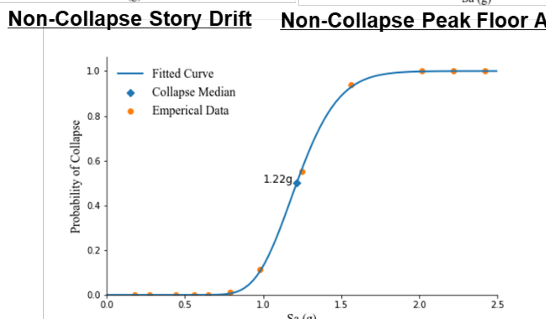
Push-over Analysis



Non-Collapse Story Drift

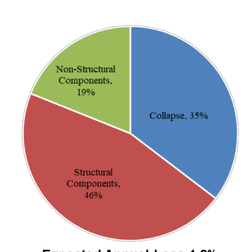


Non-Collapse Peak Floor Acceleration

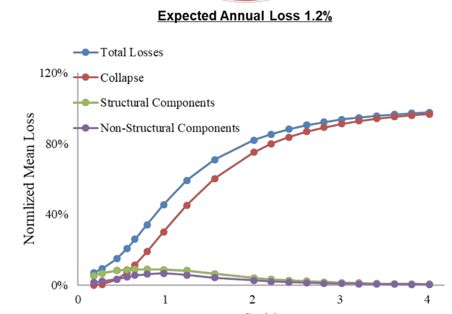


Collapse Fragility

Dynamic Analysis



Expected Annual Loss 1.2%



Intensity Based Loss

Loss Assessment

- **Parameter Variations**

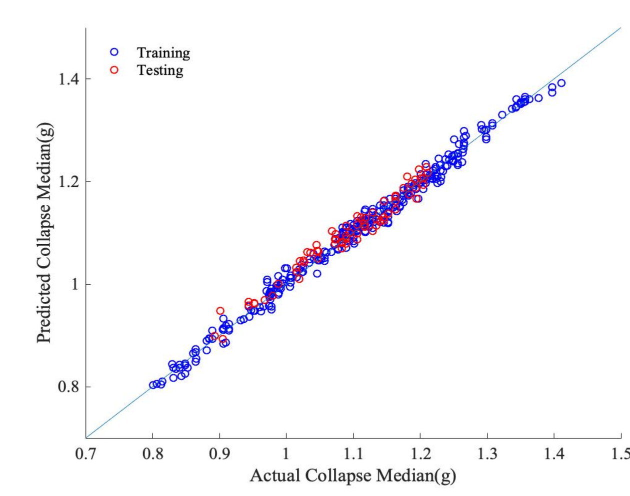
To propagate the model uncertainty, the above building prototype is used. Parameter variations are shown in the right table.

Parameter Name	Distribution	Range
Cripple Wall Height	Uniform	[2ft, 7ft]
Gypsum Deformation Shift	Normal	[Mean-2std, Mean+2std]
Gypsum Force Amplification	Normal	
Gypsum-stucco Deformation Shift	Normal	
Gypsum-stucco Force Amplification	Normal	
Stucco Deformation Shift	Normal	
Stucco Force Amplification	Normal	
Roof Weight	Uniform	[13psf, 20psf]

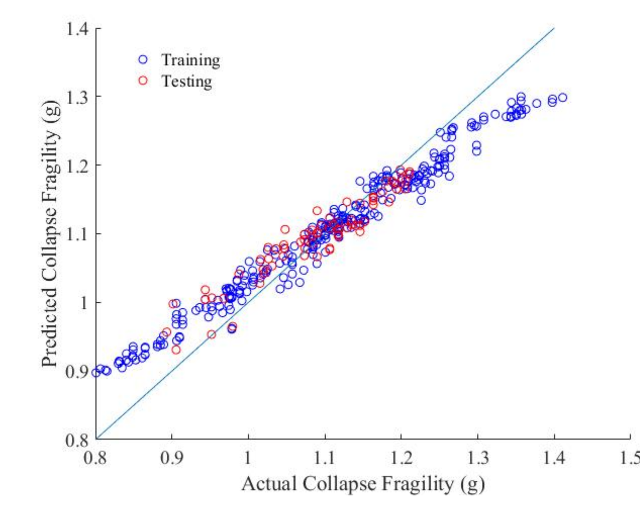
3. Uncertainty Propagation: Surrogate Models

- **Development and Verification Surrogate Models**

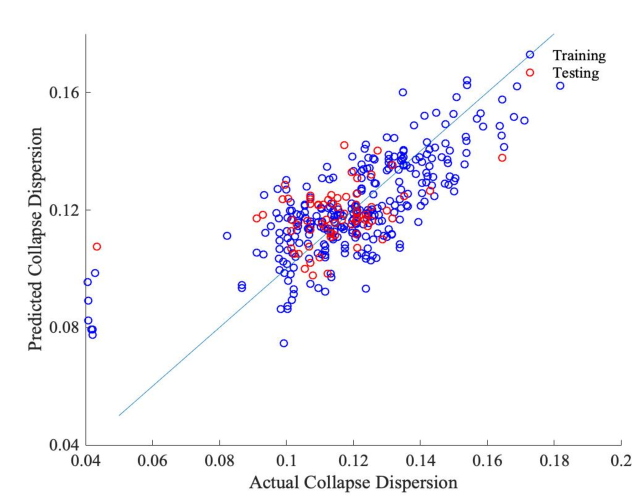
Response Surface Methodology and Random Forest are investigated to model the relationships between building parameters and structure seismic collapse risk. To reduce computational expense and meanwhile develop reliable statistical models, Central Composite Design (CCD) is adopted. Variations in 8 building collapse performance critical parameters are considered, including cripple wall height, roof weight, material force and displacement parameters. The primary focused response parameters are collapse median intensity and dispersion. Besides 289 training set generated using CCD, another separated 70 cases are developed to verify the statistical models.



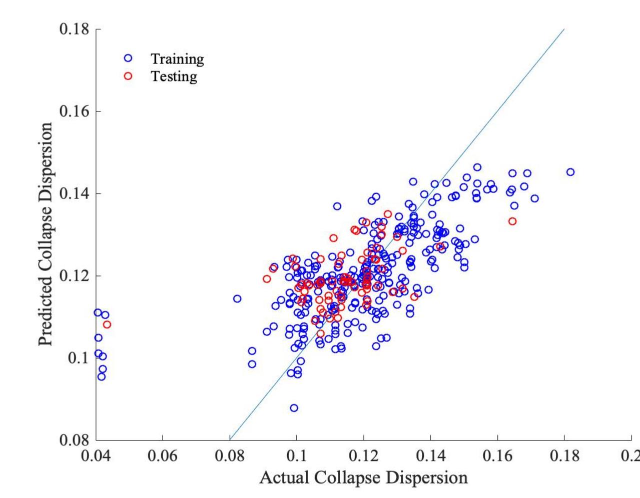
Response Surface Method Actual vs Predicted Collapse Median



Random Forest Actual vs Predicted Collapse Median



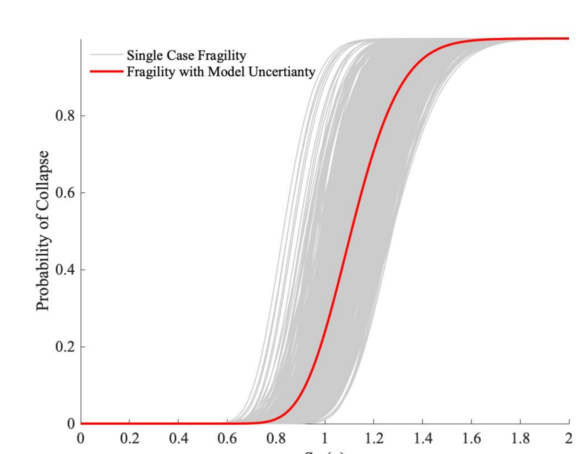
Response Surface Method Actual vs Predicted Fragility Dispersion



Random Forest Actual vs Predicted Fragility Dispersion

- **Using Surrogate Model to Perform Uncertainty Propagation**

Through comparing Response Surface Method (RSM) with Random Forest (RF), RSM can provide with unbiased and more reliable predictions. Consequently, RSM is selected to perform uncertainty propagation. Monte Carlo method is adopted, 500 random samples are generated and the corresponding collapse medians and dispersions are computed. At each intensity level, collapse or non-collapse are decided based on the probability of collapse, then accumulate all 500 cases to develop collapse fragility with model uncertainty.



RSM Collapse Fragility with Model Uncertainty

	Min	Max	Mean	Median	Dispersion
Collapse Median	0.8424g	1.3156g	1.1058g	1.1095g	0.0859g
Collapse Dispersion	0.0852	0.1703	0.1209	0.1208	0.0113

Median with Model Uncertainty	1.1027 g	Median without Model Uncertainty	1.117 g
Dispersion with Model Uncertainty	0.1440	Dispersion without Model Uncertainty	0.1208

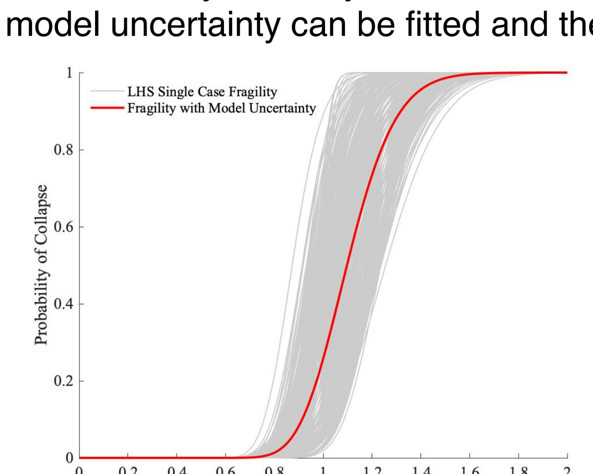
With the consideration of model uncertainty, the dispersion is about 20% higher than the dispersion without model uncertainty, which is a dramatic difference in terms of collapse risk. Using the dispersion with and without model uncertainty, model uncertainty can be computed by subtract the ground motion uncertainty.

$$\beta_M = \sqrt{\beta_T^2 - \beta_{GM}^2} = 0.079$$

4. Uncertainty Propagation: Latin Hypercube Sampling (LHS)

- **Latin Hypercube Sampling Uncertainty Propagation**

As an improvement to traditional Monte Carlo method, Latin Hypercube Sampling (LHS) can control the random samples distributed more evenly so that the effective sample size can be reduced. Considering the same parameter variations as RSM, for each parameter, using LHS to generate 500 samples. Then randomly group all the parameters to generate 500 different building models. Through performing nonlinear response history analysis (NRHA), the number of collapse cases are collected at each intensity level. By accumulate all the collapse cases from all 500 cases, a collapse fragility with model uncertainty can be fitted and the total uncertainty is the fragility dispersion.



LHS Collapse Fragility with Model Uncertainty

	Min	Max	Mean	Median	Dispersion
Collapse Median	0.873g	1.2561g	1.1007g	1.1063g	0.0816g
Collapse Dispersion	0.0396	0.1637	0.1177	0.1165	0.0171

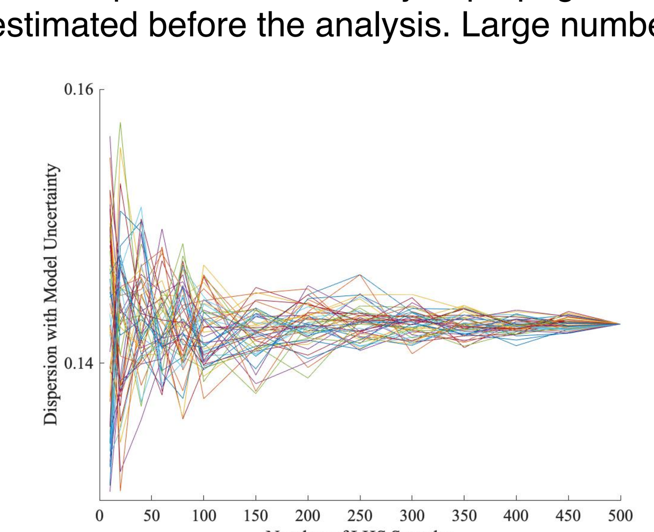
Median with Model Uncertainty	1.0976g	Median without Model Uncertainty	1.117g
Dispersion with Model Uncertainty	0.1428	Dispersion without Model Uncertainty	0.1208

LHS gives very similar results to RSM. With the consideration of model uncertainty, the total dispersion is 19% higher than without model uncertainty. The model uncertainty is as following.

$$\beta_M = \sqrt{\beta_T^2 - \beta_{GM}^2} = 0.076$$

- **Latin Hypercube Sampling Convergence Check**

LHS provides with a way to propagate uncertainties, but the number of required samples cannot be estimated before the analysis. Large number of samples should be first tried and convergence is checked.



LHS Number of Samples vs Collapse Dispersion with Model Uncertainty

Number of Samples	Mean	Median	Standard Deviation
10	0.142	0.143	0.0074
20	0.142	0.141	0.0056
40	0.142	0.142	0.0034
60	0.143	0.142	0.0033
80	0.143	0.142	0.0025
100	0.142	0.142	0.0023
150	0.143	0.143	0.0016
200	0.143	0.143	0.0015
250	0.143	0.143	0.0009
300	0.143	0.143	0.0009
350	0.143	0.143	0.0007
400	0.143	0.143	0.0006
450	0.143	0.143	0.0004

Through convergence checking, 500 LHS samples can provide stable estimation of collapse risk with model uncertainty.

5. Conclusion

- Statistical models and Latin Hypercube Sampling can be used to quantify the model uncertainties in wood-frame building single family residence collapse performance. Both method can reach an agreement to the propagated uncertainty.
- For the current building prototype, with the consideration of model uncertainty, the total dispersion would increase about 20%, which makes a difference in building seismic performance.
- For statistical models, Response Surface Method is more robust than Random Forest, because it gives unbiased predictions.
- For the purpose of uncertainty quantification, Response Surface Method is computationally less intensive than Latin Hypercube Sampling Method, because it requires about 40% less nonlinear history analysis than LHS.

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