Probabilistic PBEE Applications

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Outline

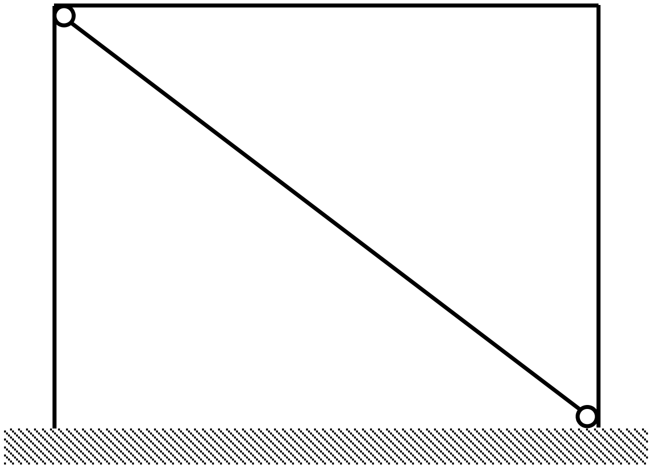
1. **Application I**: Evaluation of the effect of unreinforced masonry infill walls on reinforced concrete frames with probabilistic PBEE
2. **Application III**: PEER PBEE assessment of a shearwall building located on the University of California, Berkeley campus
3. **Application II**: Evaluation of the seismic response of structural insulated panels with probabilistic PBEE

Application I

Evaluation of The Effect of Unreinforced Masonry Infill Walls on Reinforced Concrete Frames with Probabilistic PBEE

Application I

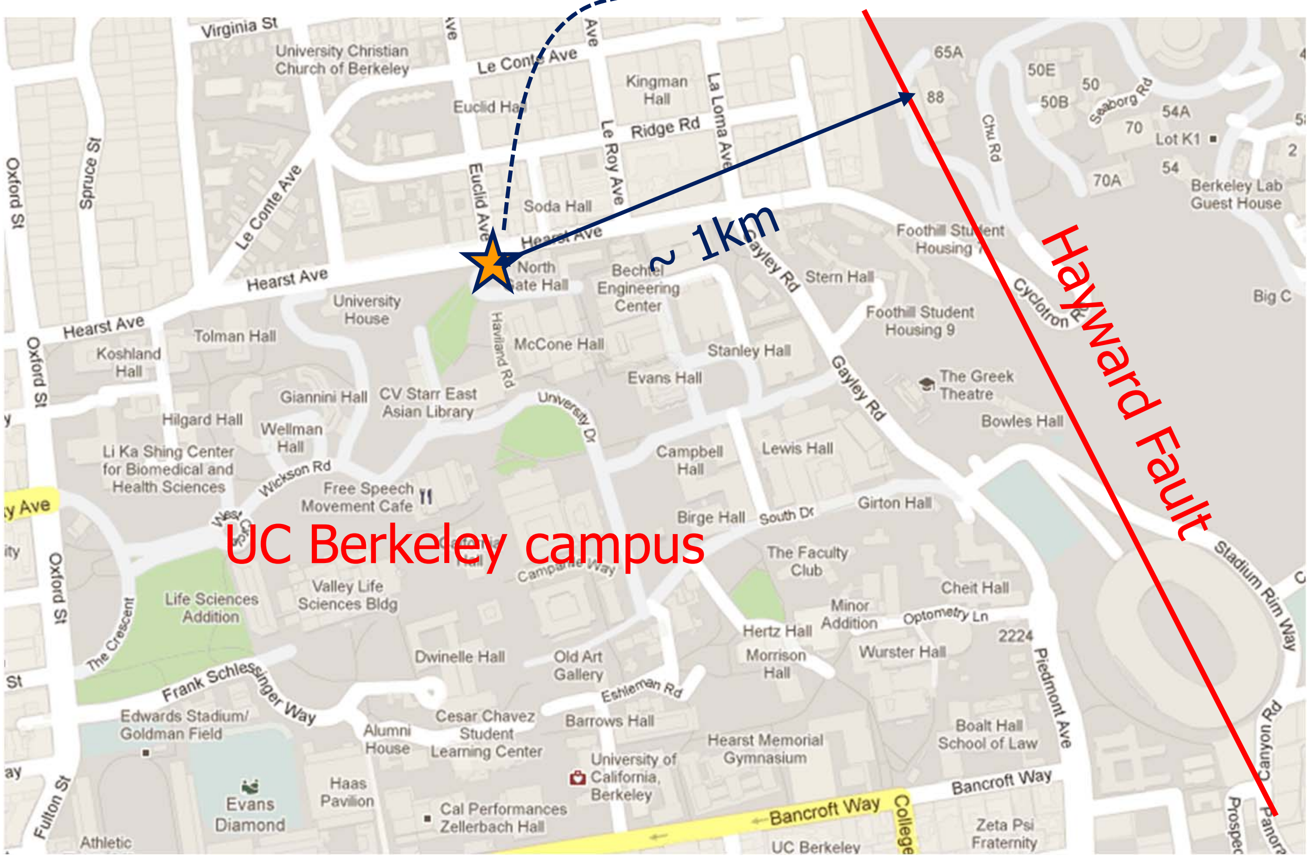
- An idealized portal frame **with and without** infill
- Demonstration of **hazard and structural analyses**
- The geometry of the portal frame based on the dimensions of a single story RC frame with infill wall tested on UC-Berkeley shaking table [Hashemi & Mosalam, 2006].



Application I

Hazard Analysis

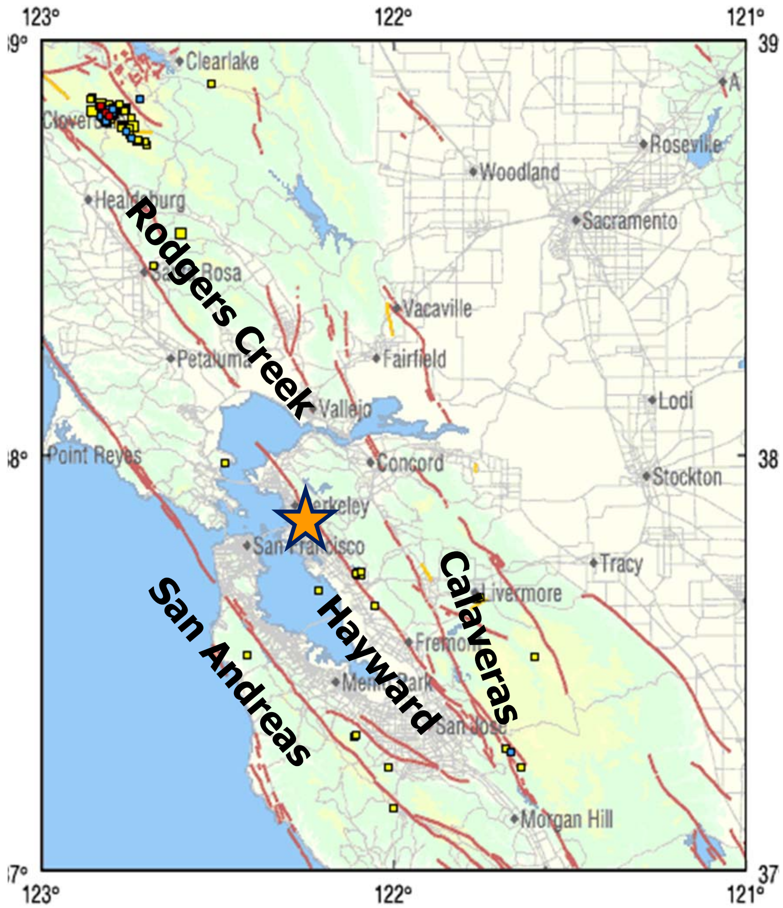
Location of the structure:
@North gate of campus
(37.877°, -122.264°)



Site class:
NEHRP D

Application I

Hazard Analysis



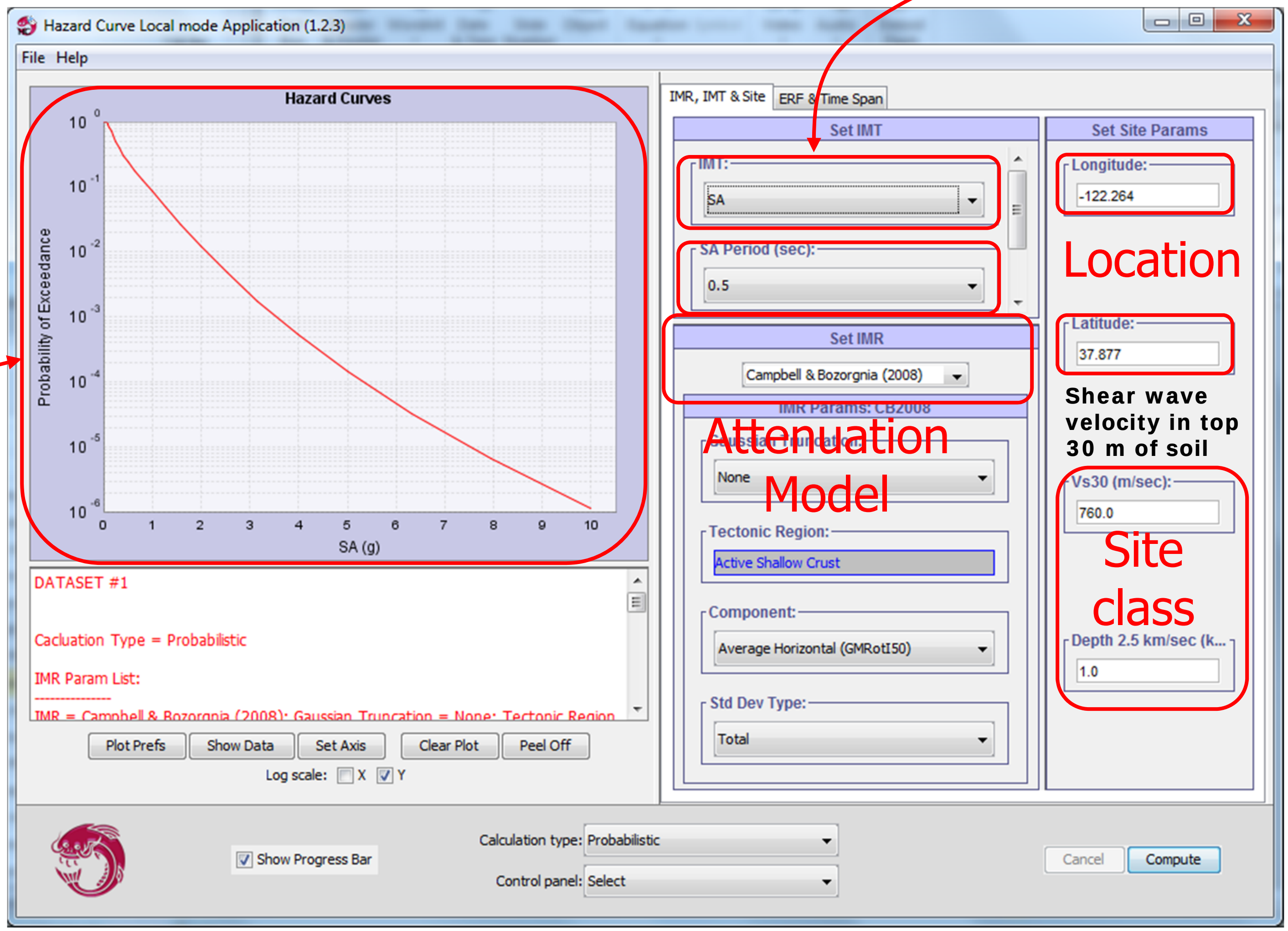
Source: USGS

Application I

Hazard Analysis

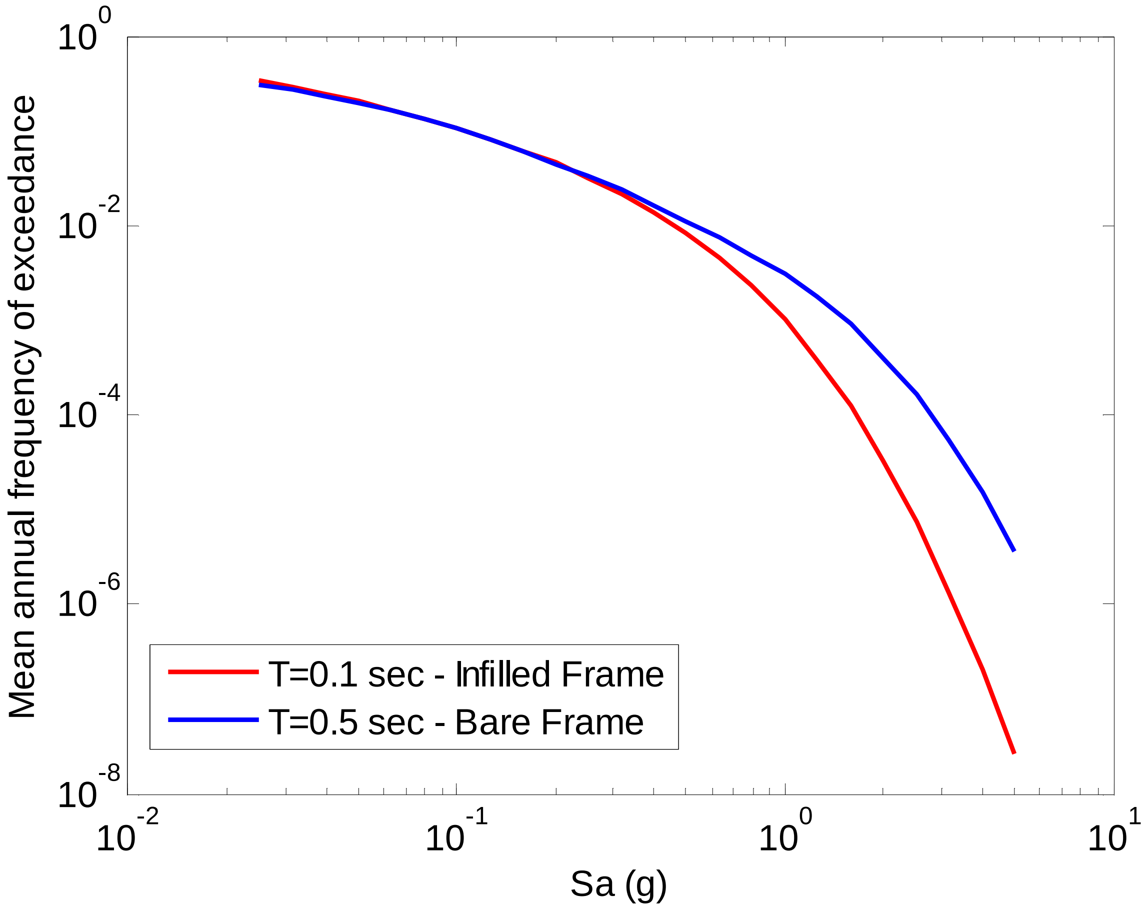
$$P(\mathrm{IM}) = 1 - e^{-\lambda(\mathrm{IM})\,T}, T = 50 \text{ years} \Rightarrow \lambda(\mathrm{IM})$$

OpenSHA
http://www.opensha.org



Application I

Hazard Analysis: Hazard Curve

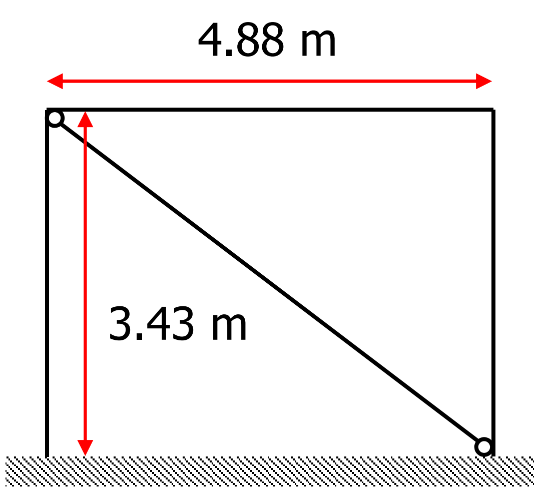


Hazard is more severe for the bare frame at this particular location

Application I

Structural Analysis

- Analytical modeling using OpenSees [2010]
- Force-based beam-column elements with fiber discretized sections
- Material for core and cover concrete: Concrete02
- Material for reinforcing bars: Steel01
- Material strengths [Hashemi & Mosalam, 2006]
  - Concrete: f_c' beam = 37 Mpa, f_c' columns = 38 Mpa
  - Steel: f_y = 458 MPa
- Sections:
  - Columns: 305×305 mm square section
  - Beam: 343×267 mm rectangular section
- Reinforcement:
  - Columns: Longitudinal: eight #6, Transverse: #3@95 mm
  - Beam: Longitudinal: three #6 bars (top and bottom), Transverse: #3@70 mm



Transverse reinforcement used to determine core concrete strength

Application I

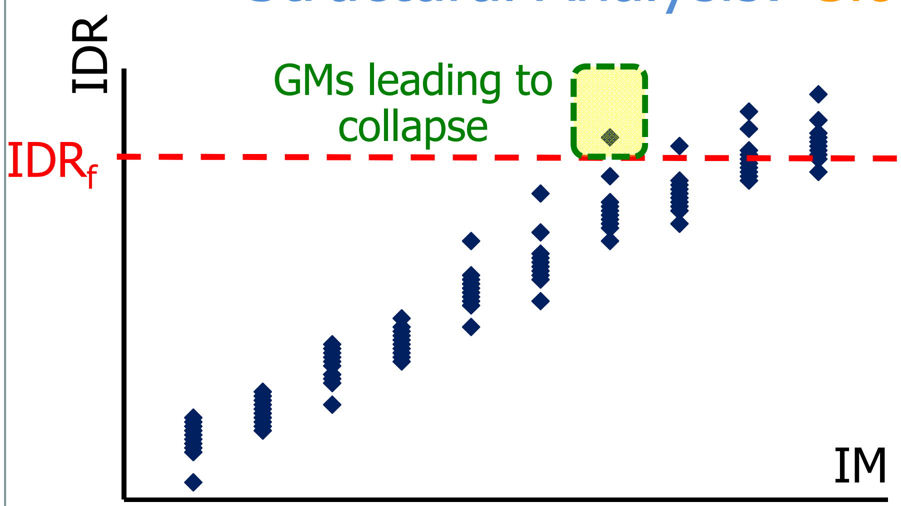
Structural Analysis

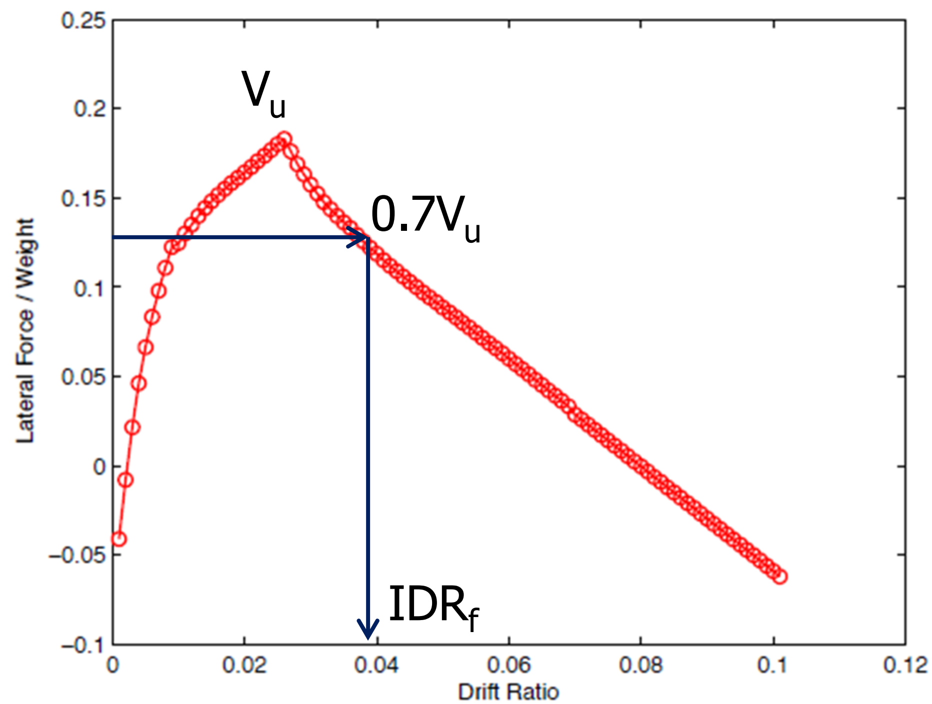
- Twenty ground motions [Lee & Mosalam, 2006] used in nonlinear time history analyses (explanation later in Application III)
- Ground motions scaled for each of the considered $Sa(T_1)$ value

  Note: Use of unscaled ground motions should be the preferred method in a real-life application
- For demonstration purposes, only uncertainty in ground motion is considered; material uncertainty is not taken into consideration
- Total number of analyses conducted for an intensity level is twenty
- Peak interstory drift ratio (IDR) & peak roof acceleration (RA) are considered as the EDPs

Application I

Structural Analysis: Global collapse determination



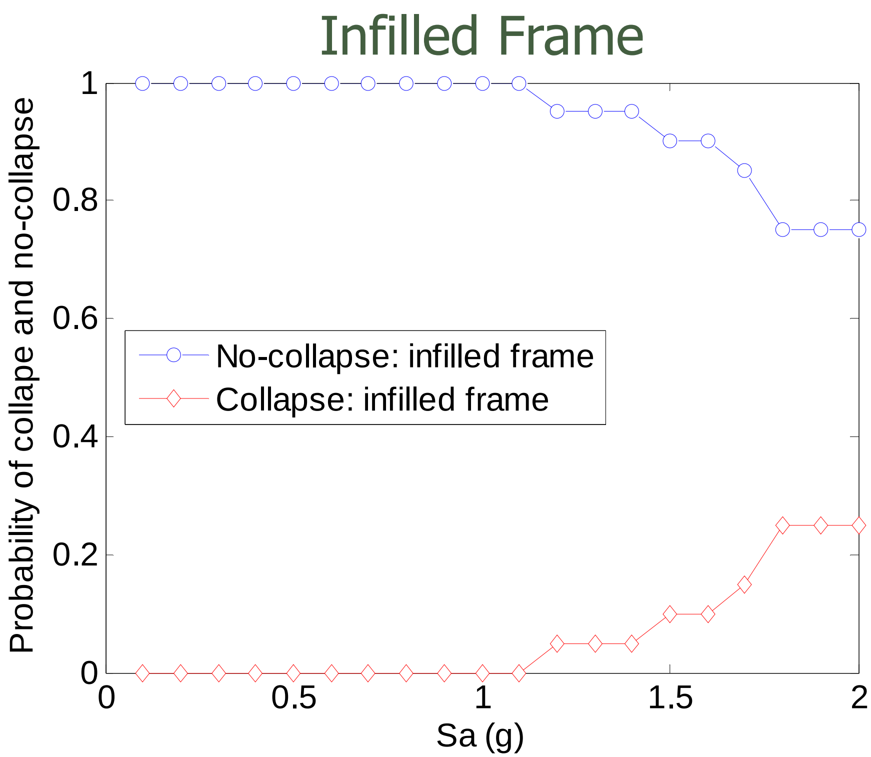


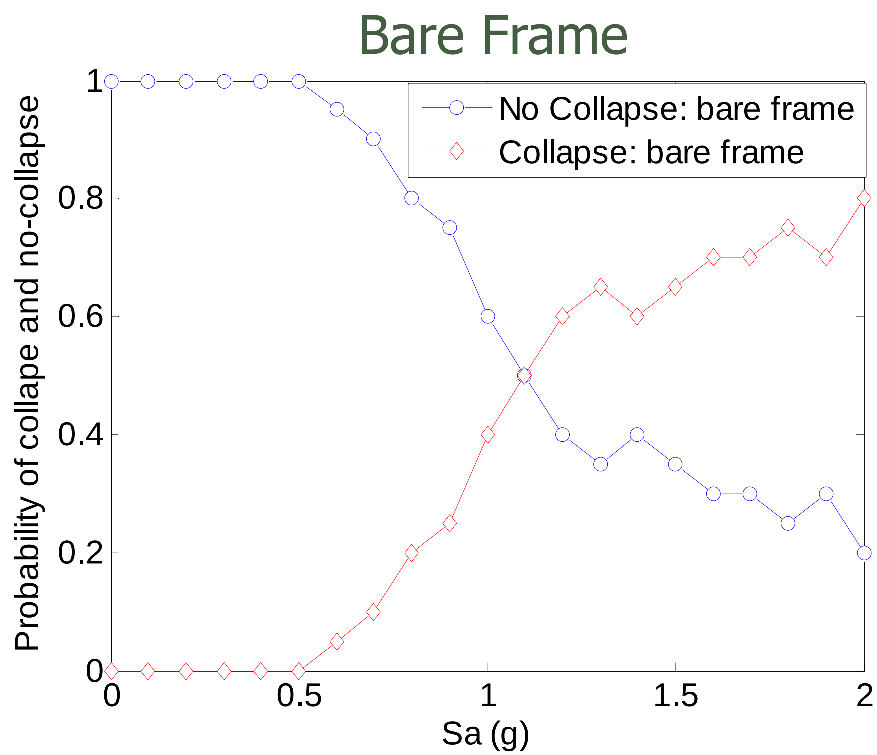
p(C|IM) =

# of GMs leading to collapse / total # of GMs

Application I

Structural Analysis: Global collapse determination





Collapse probability is much less for the infilled frame case for all intensity levels: specific for this frame

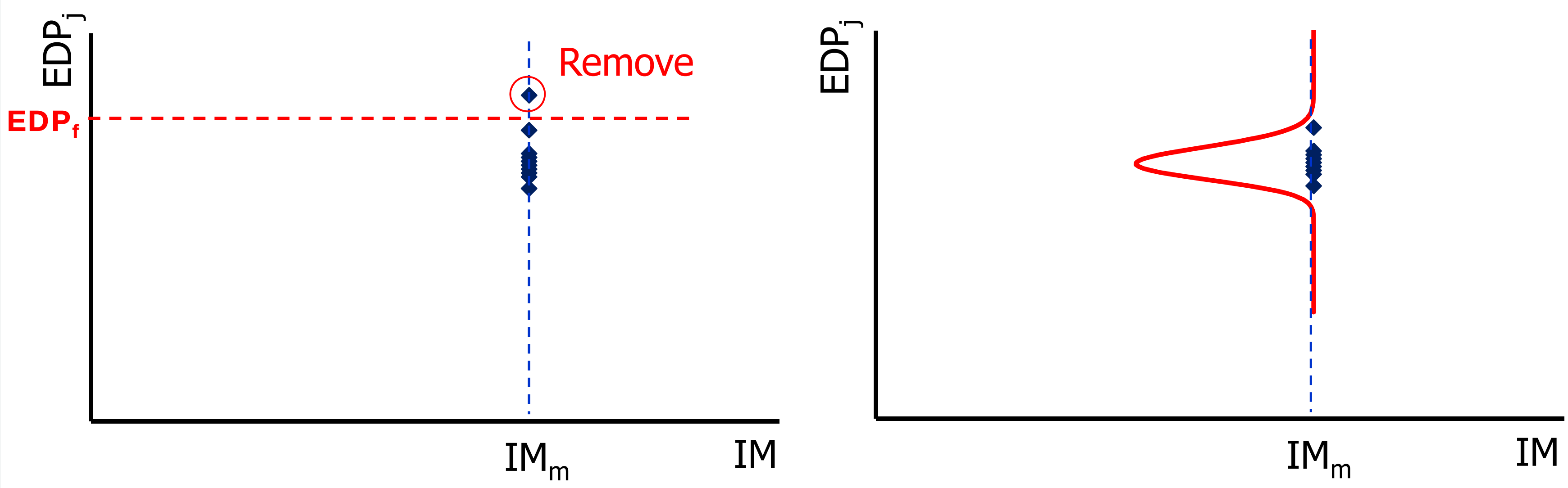
In a multistory, three-dimensional (3D) frame:

- Sudden failure of infill walls can lead to weak stories, which is usually followed by a global collapse
- Shear failure can be critical for the columns because of the lateral component of the force transferred by the infill wall

Structural Analysis

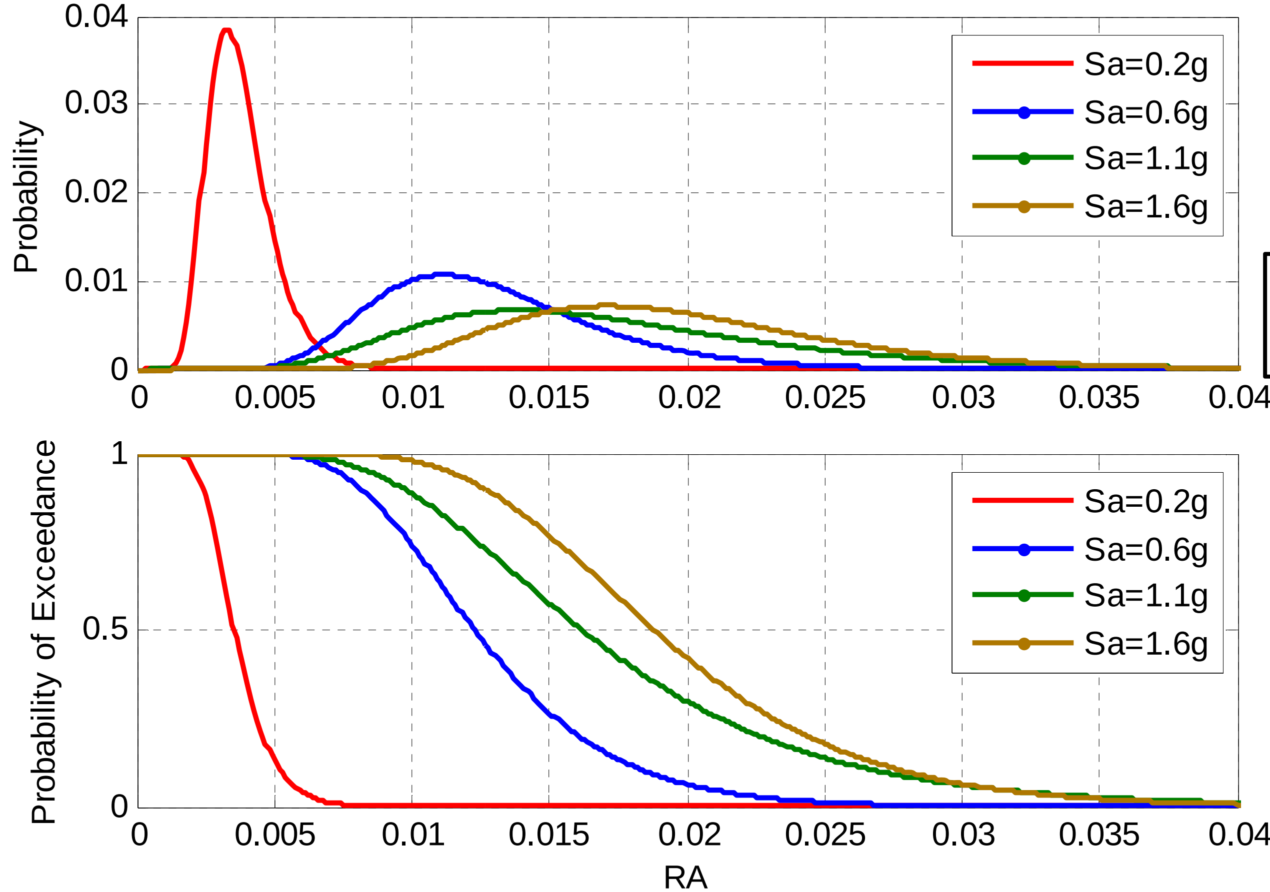
Outcome of Structural Analysis:

Probability of each value (index i) of each EDP (index j) for each hazard level (index m): $p(EDP_j^i|Im_m)$



Application I

Outcome of Structural Analysis: Probability and POE for IDR and RA "Only RA is shown here"



Lognormal distribution

Application I

Combination of Hazard and Structural Analyses

Total probability theorem:

Given n mutually exclusive events* $A_1, \ldots, A_n$ whose probabilities sum to 1.0, then the probability of an arbitrary event B:

$$p(B) = p(B|A_1)\,p(A_1) + p(B|A_2)\,p(A_2) + \ldots + p(B|A_n)\,p(A_n)$$

$$p(B) = \sum_i p(B|A_i)\,p(A_i)$$

Conditional probability of B given the presence of A_i

Probability of A_i

*Occurrence of any one of them automatically implies the non-occurrence of the remaining n−1 events

Application I

Combination of Hazard and Structural Analyses

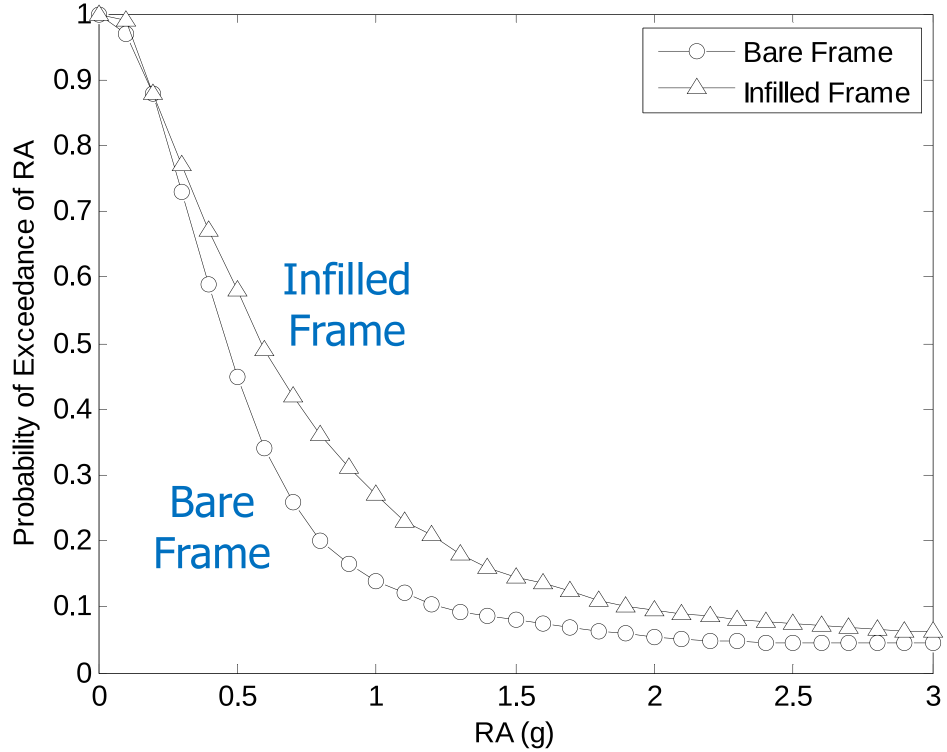
$$P(EDP^i) = \sum_m P(EDP^i | IM_m)\, p(IM_m)$$

$$P(RA^i) = \sum_m P(RA^i | Sa_m)\, p(Sa_m) \qquad P(IDR^i) = \sum_m P(IDR^i | Sa_m)\, p(Sa_m)$$

m: index for IM   i: index for EDP

Application I

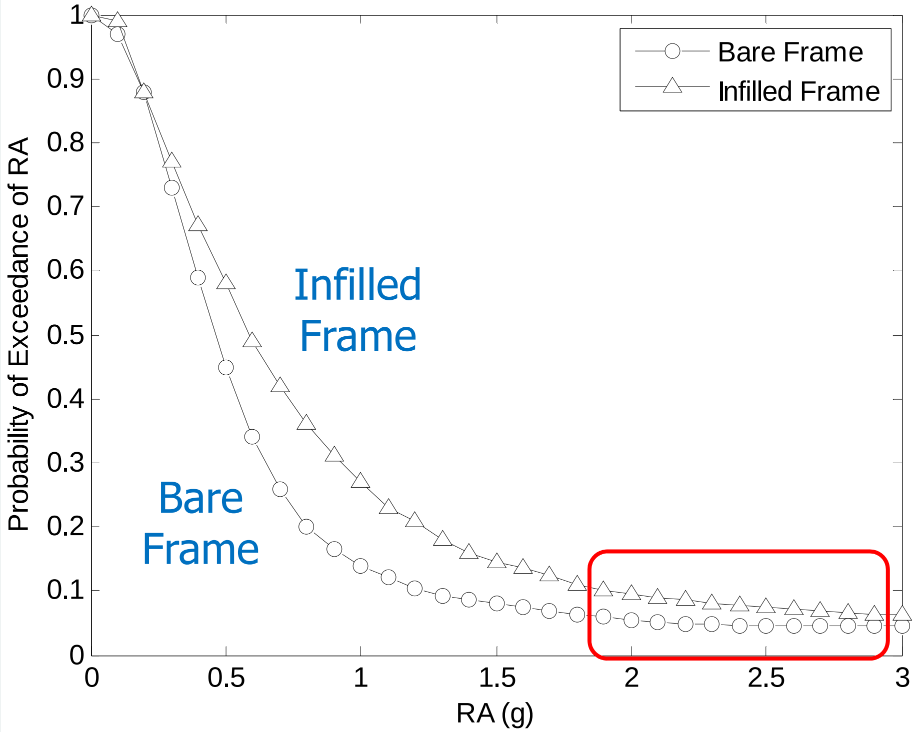
Combination of Hazard and Structural Analyses



- POE of RA is larger for the infilled frame <u>due to:</u>
  - Initial periods for small RA values (acceleration response for 0.1 sec - infilled frame is greater than that for 0.5 sec - bare frame)
  - Lateral force capacity (larger for the infilled frame compared to the bare frame) for large SA

Application I

Combination of Hazard and Structural Analyses



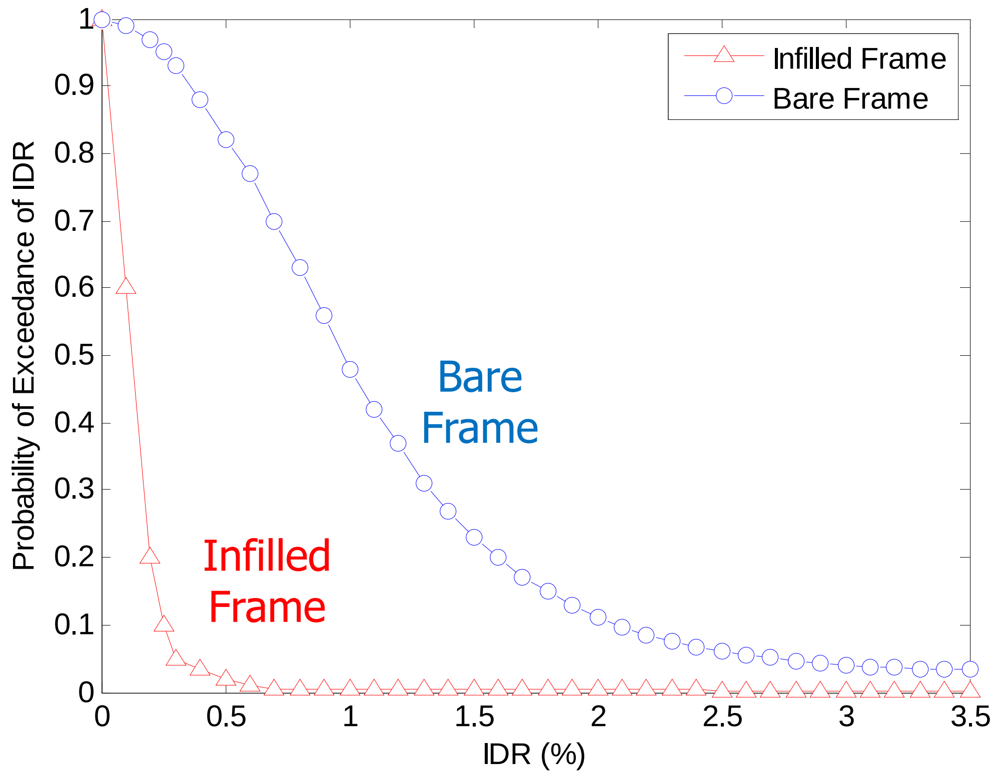
Remark:

- For each of the intensities in this region, RA is dominated by the lateral force capacity
- However, POE of RA of the two frames gets closer to each other as RA increases
- This is mainly because of the probability of Sa, p(Sa_m), which can be considered as a weighing factor, is smaller for the infilled frame for a large value of Sa

- Benefit of combining different analyses stages:
  - Results of structural analysis alone would indicate larger POE of the RA response for the infilled frame than that for the bare frame for larger intensities
  - However, combination of the two analyses indicates that the POEs of the RA response of the bare and infilled frames are comparable for large intensities

Application I

Combination of Hazard and Structural Analyses



- ❑ POE of IDR of the bare frame is much larger than that of the infilled frame
- ❑ Significant contribution of the infill wall in reducing the frame deformation response
- ❑ Specific to the portal frame analyzed in this application and the adopted modeling assumptions → Should not be generalized

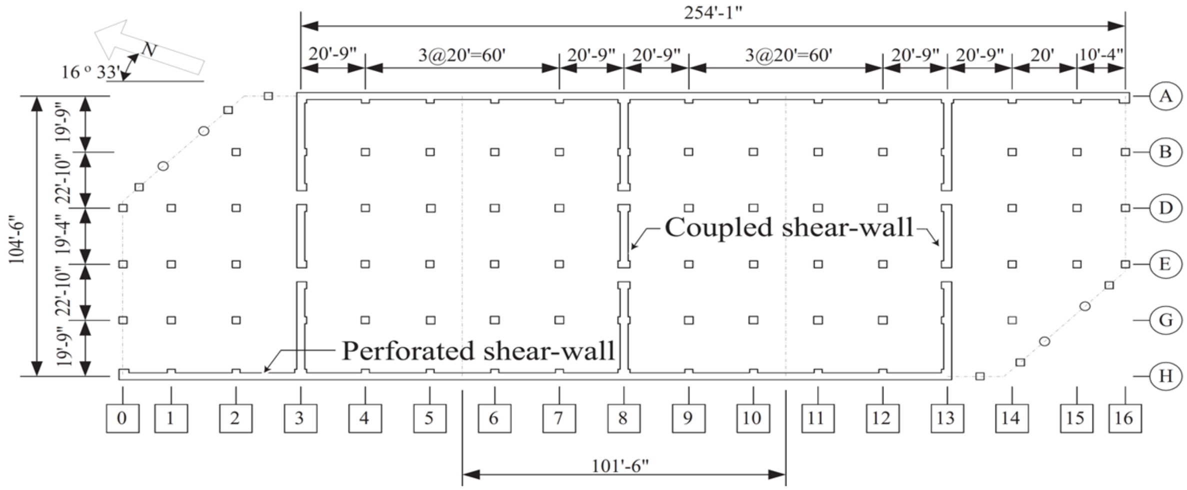
Application III

PEER PBEE Assessment of a Shearwall Building Located on the University of California, Berkeley Campus

Application III

- University of California Science (UCS) building in UC-Berkeley campus
- Modern reinforced concrete shear-wall building
- High technology research laboratories for organismal biology, animal facilities, offices and related support spaces
- An example for which non-structural components contribute to the PBEE methodology due to valuable building contents, i.e. the laboratory equipment and research activities

Application III

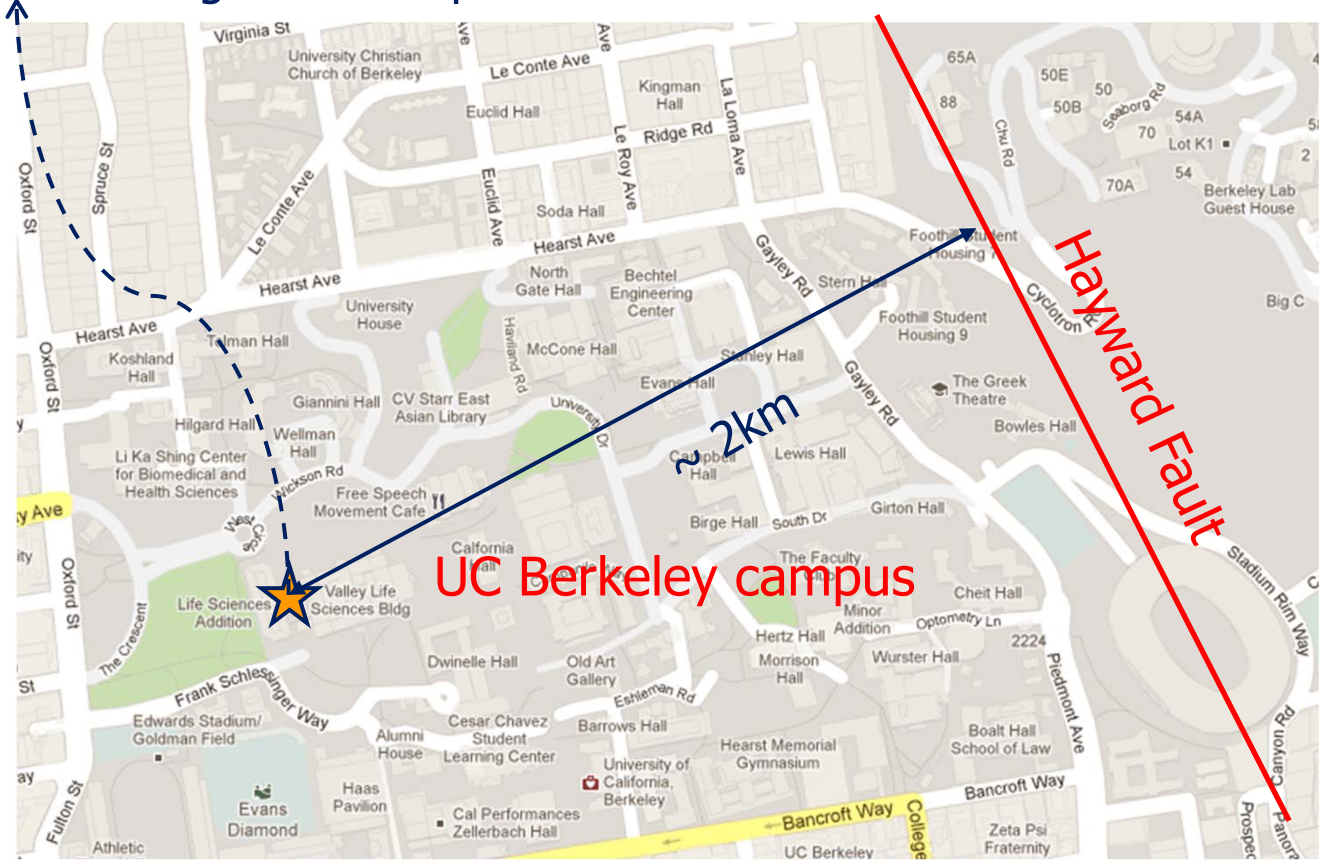


- Six stories and a basement
- Rectangular in plan with overall dimensions of approximately 93.27 m x 32 m
- **Gravity load resistance**: RC space frame
- **Lateral load resistance**: Coupled and perforated shearwalls
- Floors consist of waffle slab systems
- Waffle slab is composed of a 114 mm thick RC slab supported on 508 mm deep joists in each direction.
- Foundation consists of a 965 mm thick mat

Application III

Hazard Analysis

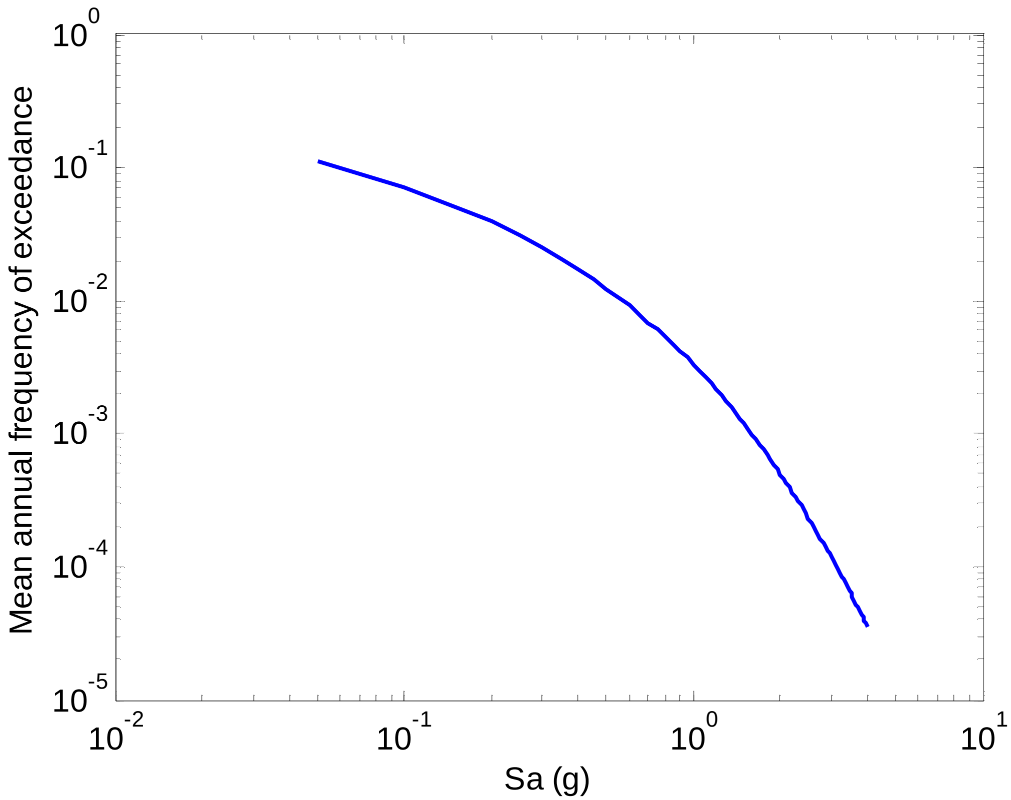
Location of the structure:
close to west gate of campus



Site class:
NEHRP C

Application III

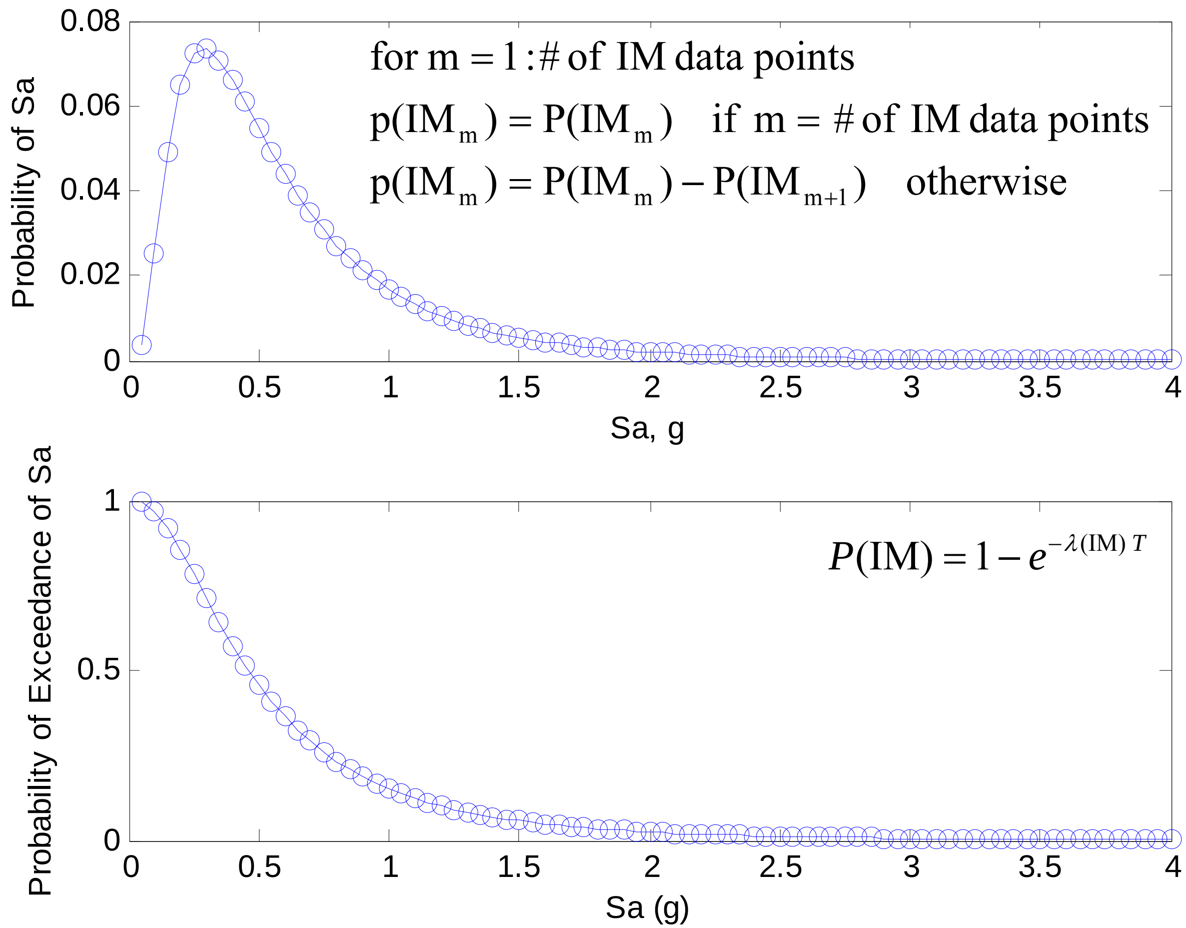
Hazard Analysis: Hazard Curve



- Lognormal distribution of Sa with the mean of 0.633g and standard deviation of 0.526g
- Matches with MAF of exceedance of Sa at periods of 0.2, 0.3 and 0.5 seconds reported by Frankel and Leyendecker [2001]

Application III

Hazard Analysis: Probability and Probability of Exceedance



Application III

Structural Analysis

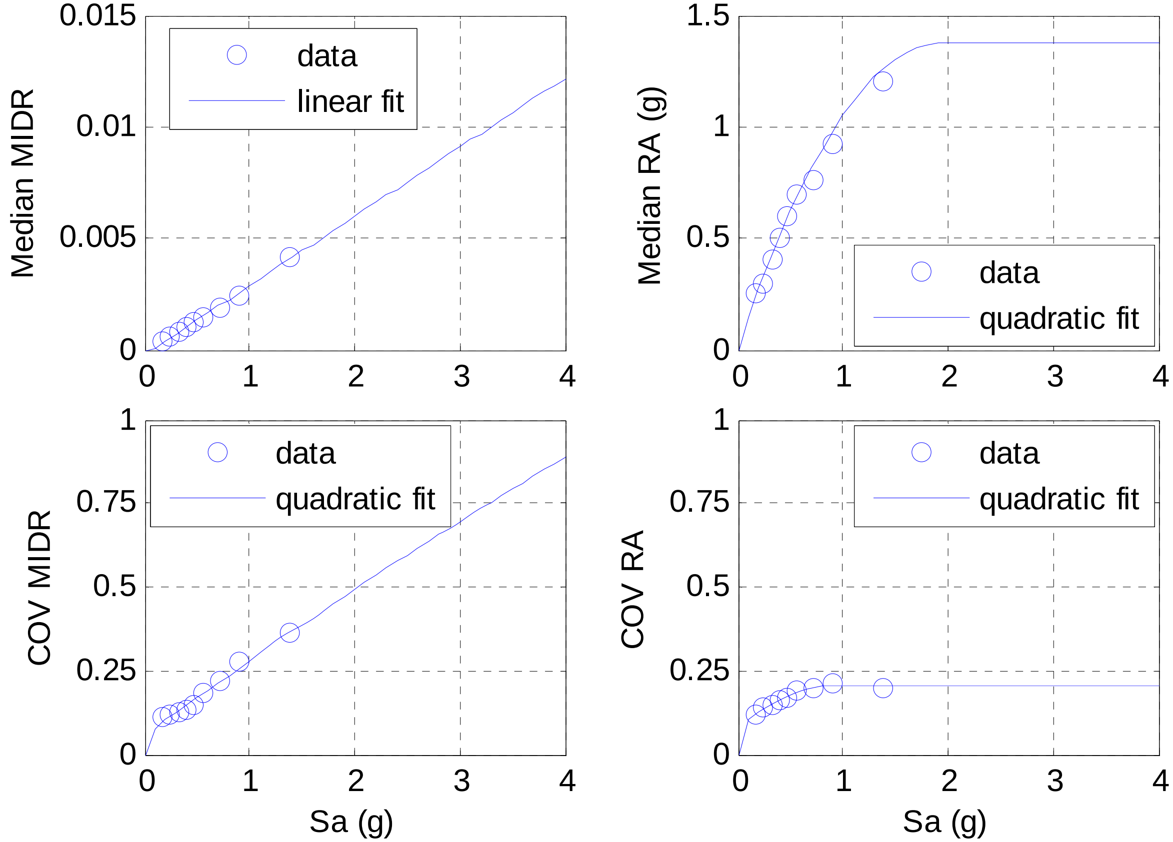
- Two damageable groups
  - Structural components: EDP= Maximum peak interstory drift ratio along the height (MIDR)
  - Non-structural components: EDP = peak roof acceleration (RA)
- Twenty ground motions
  - Same site class as the building site and
  - Distance to a strike-slip fault similar to the distance of the UCS building to Hayward fault
- Nonlinear time history analyses conducted for nine different scales for each ground motion

POE(%)	90	80	70	60	50	40	30	20	10
Sa (g)	0.18	0.25	0.32	0.39	0.47	0.57	0.71	0.90	1.39
Level #	1	2	3	4	5	6	7	8	9

Application III

Structural Analysis

- For other scales, median and COV are extrapolated by curve fitting



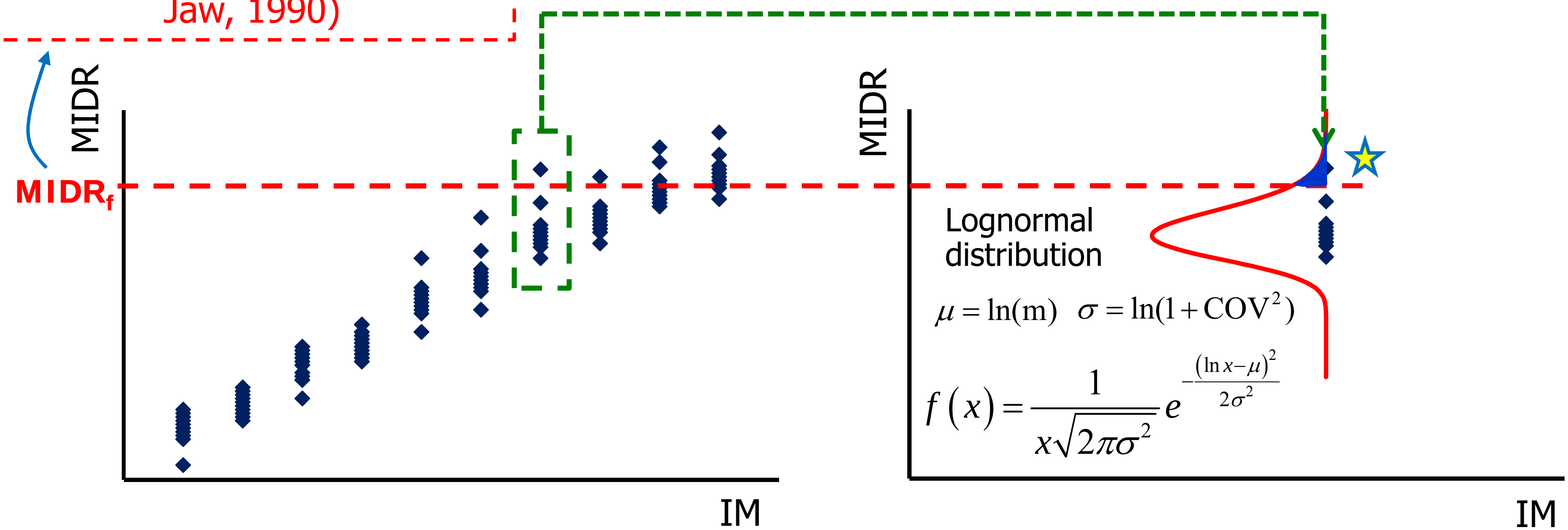
Remember: Similar concept in the optimization based design example: Aslani & Miranda, 2005

Application III

Structural Analysis: Global collapse determination

Tests of shearwall specimens: median capacity (Hwang & Jaw, 1990)

Median (m), Coefficient of variation (COV)

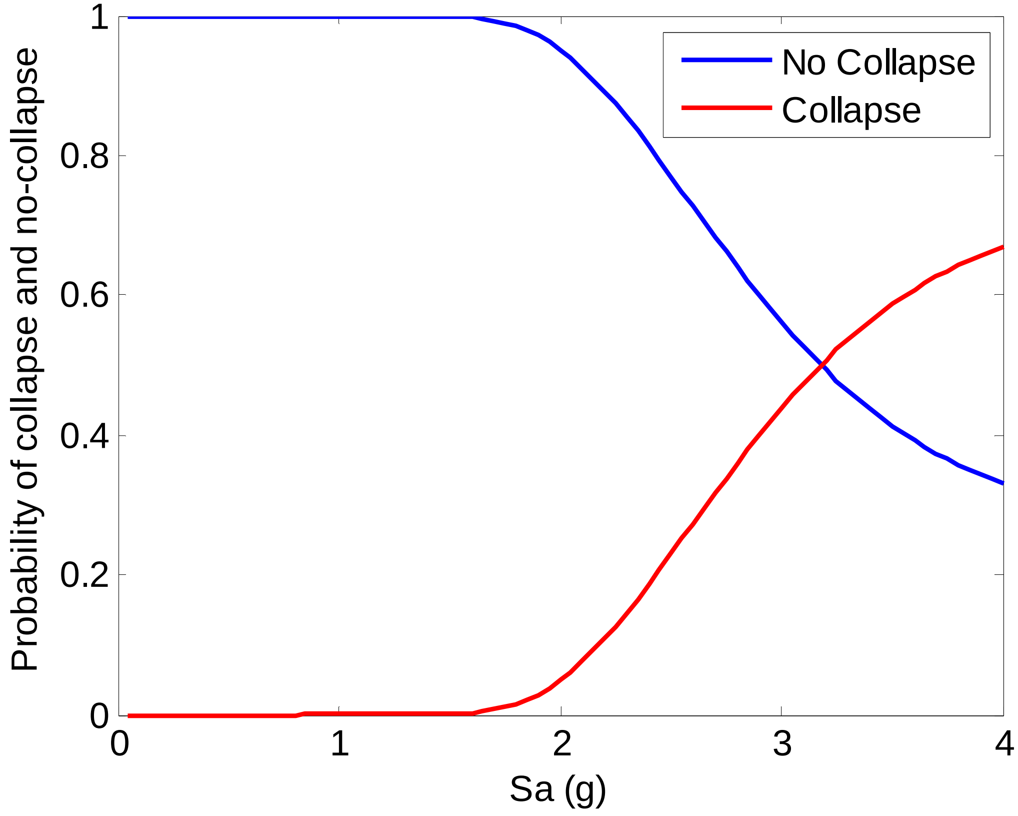


a) p(C|IM) = # of GMs leading to collapse / total # of GMs

b) p(C|IM) = shaded area ☆

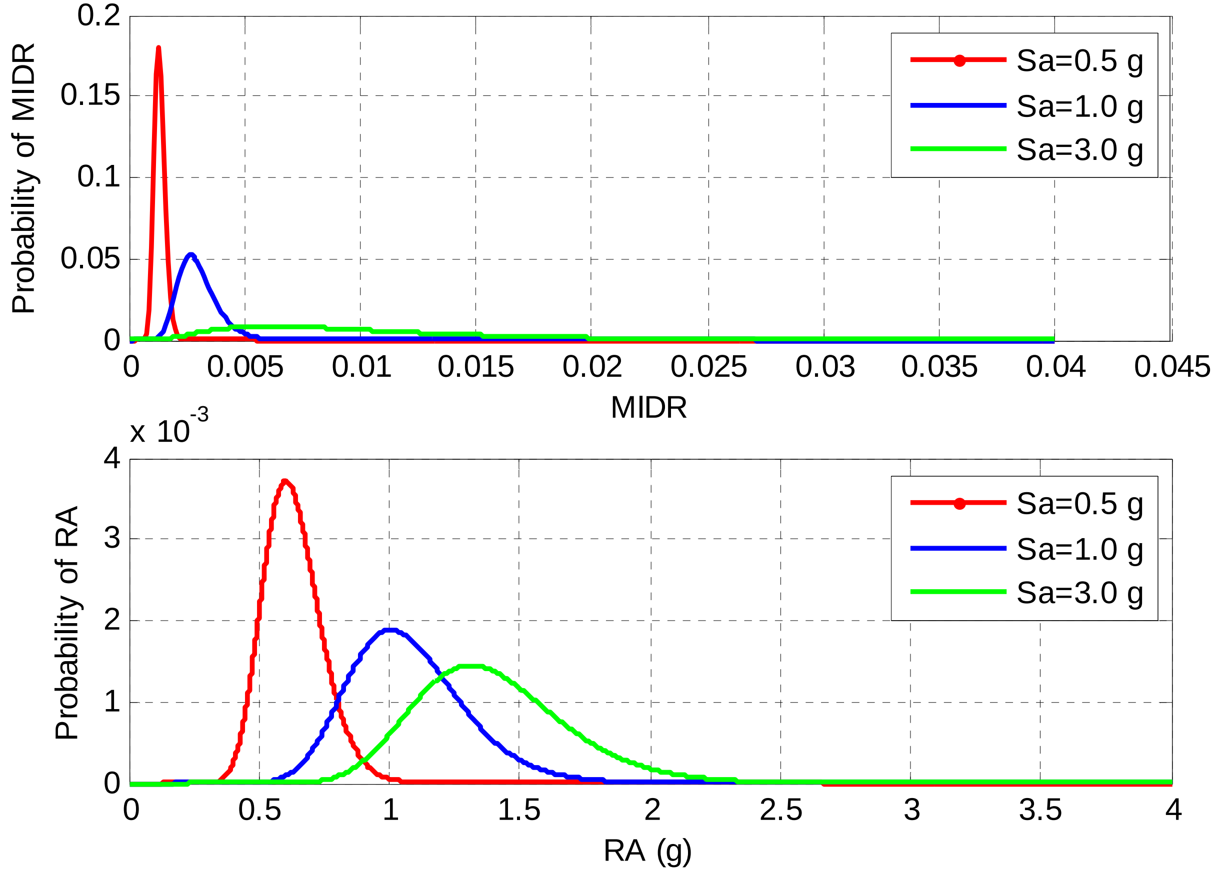
Application III

Structural Analysis: Global collapse determination



Application III

Outcome of Structural Analysis: Probability of MIDR and RA



Application III

Damage Analysis

- Damage levels considered for structural components:
  - Slight
  - Moderate
  - Severe
- Damage levels of non-structural components: Two levels based on the maximum sliding displacement experienced by the scientific equipment relative to its bench-top surface [Chaudhuri and Hutchinson, 2005]
  - Sliding displacement of 5 cm
  - Sliding displacement of 10 cm

Application III

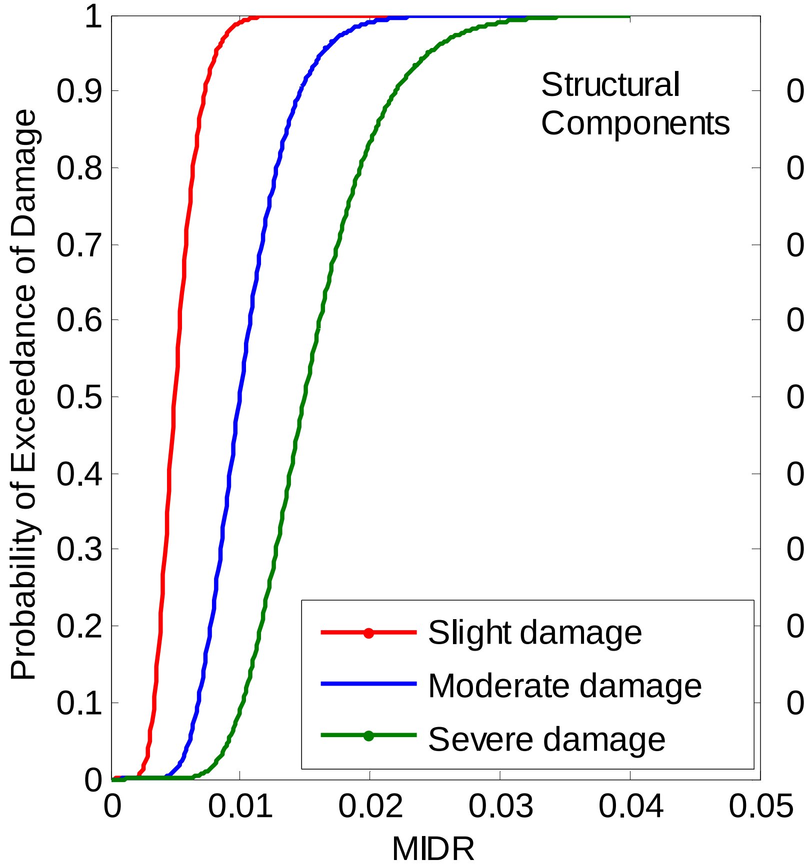
Damage Analysis

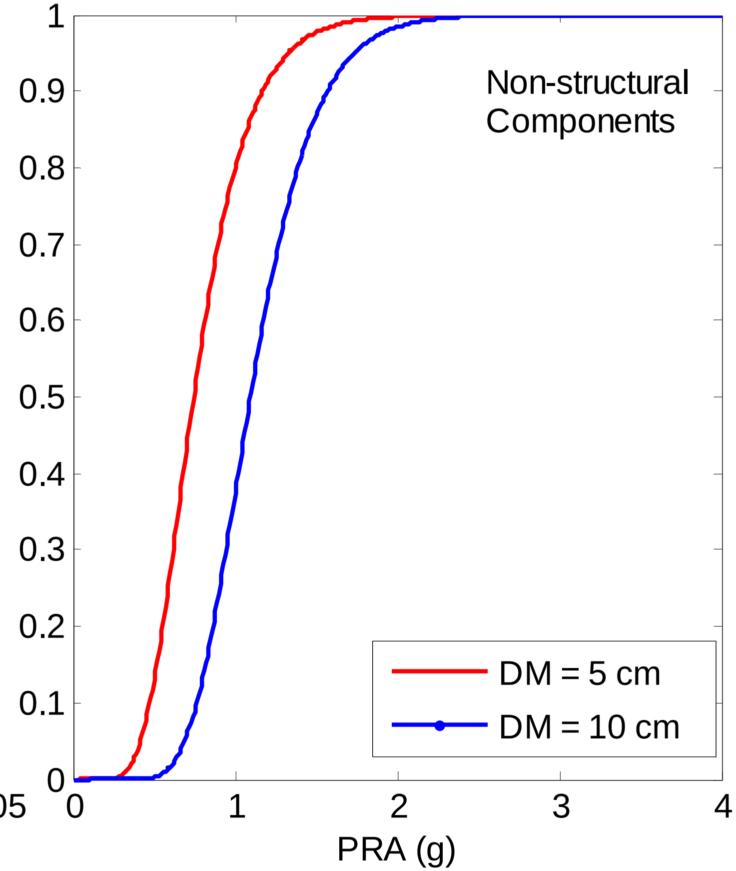
- The probability of a damage level given a value of the EDP, $p(DM_k|EDP_j^i)$, is assumed to be lognormal with defined median & logarithmic standard deviation values:
  - Structural components: shearwall tests reported in Hwang and Jaw [1990]
  - Nonstructural components: shake table tests of Chaudhuri and Hutchison [2005]

Component	Damage level	EDP	Median	Coefficient of variation
Structural	Slight	MIDR	0.005	0.30
	Moderate	MIDR	0.010	0.30
	Severe	MIDR	0.015	0.30
Non-structural	DM = 5 cm	PRA (g)	0.005	0.35
	DM = 10 cm	PRA (g)	0.010	0.28

Application III

Damage Analysis: Fragility Curves





Application III

Loss Analysis

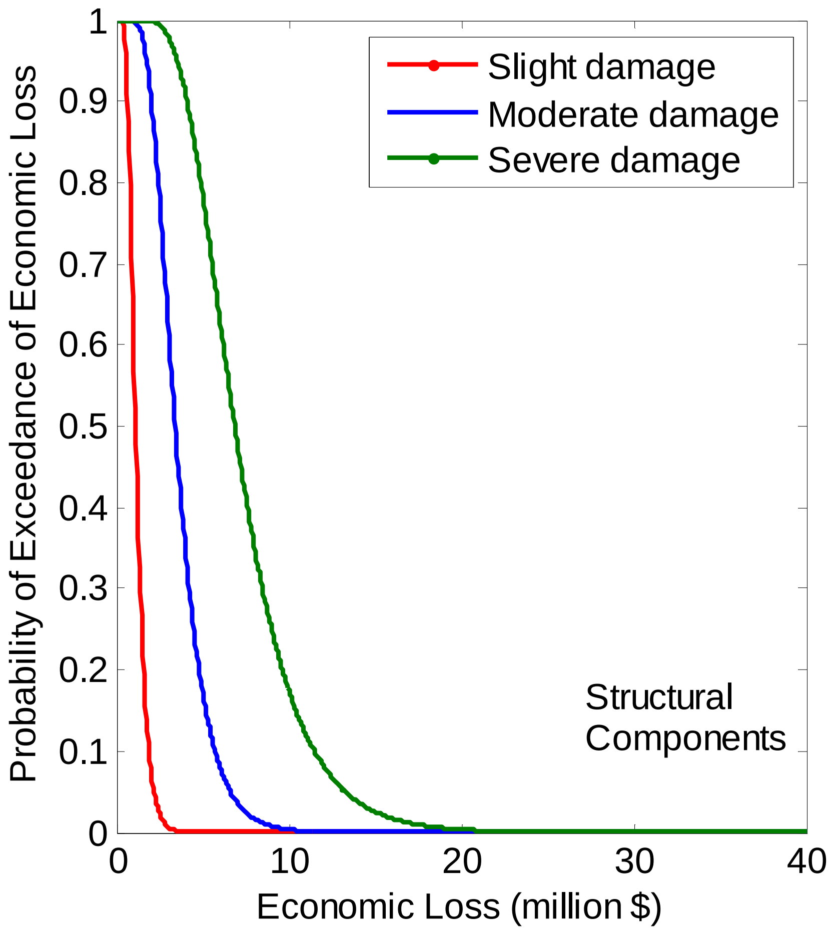
- ❑ Decision variable (DV): **monetary loss**
- ❑ The total value of the scientific equipment [SE] ≈ **$23 million** [Comerio, 2005]
- ❑ **Loss functions**: lognormal with median and coefficient of variation (COV):

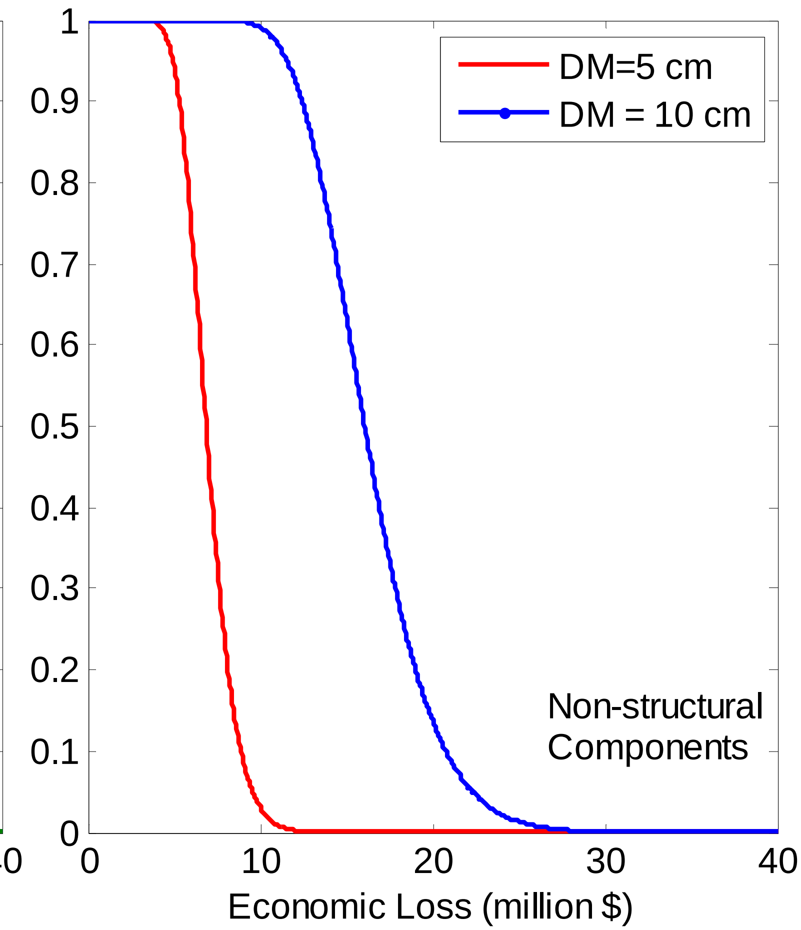
Component	Damage level	Median Loss ($million) [Percent of total value of SE]	Coefficient of variation
Structural	Slight	1.15 [5%]	0.4
	Moderate	3.45 [15%]	0.4
	Severe	6.90 [30%]	0.4
Non-structural	DM = 5 cm	6.90 [30%]	0.2
	DM = 10 cm	16.10 [70%]	0.2

Larger variation due to lack of information

Application III

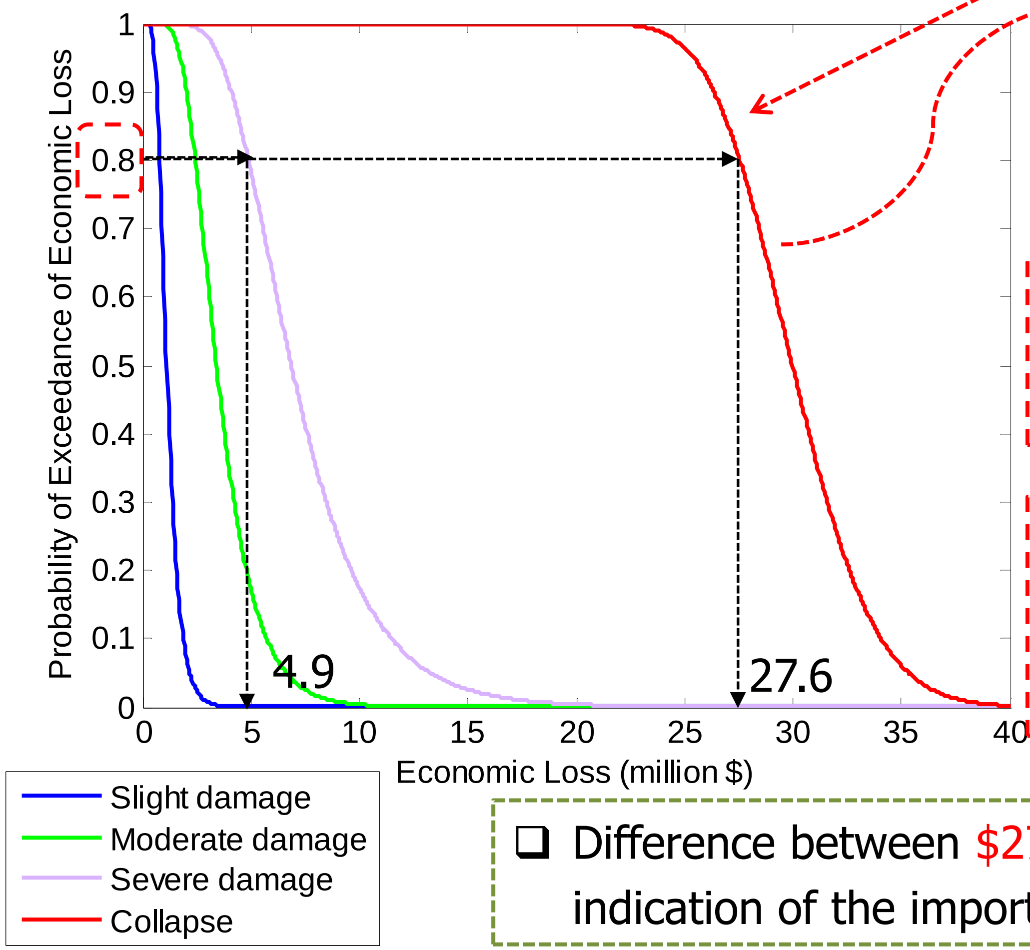
Loss Analysis: Loss Functions





Application III

Loss Analysis: Loss Function for Collapse



- Median of $30 million (total value of structural & nonstructural components)
- COV :0.2

- In case that collapse occurs, the probability of monetary loss being greater than $27.6 million is 0.8

- In case that structural components are severely damaged, the probability of monetary loss being greater than $4.9 million is 0.8

- Difference between $27.6 million and $4.9 million is a clear indication of the importance of nonstructural components

Application III

Combination of Analyses

Hazard Analysis

End product: $P(DV^n) = \sum_m P(DV^n|IM_m)\, p(IM_m)$

POE of the n[th] value of the DV of the facility

Structural Analysis: Probability of no-collapse & of collapse

$$P(DV^n|IM_m) = P(DV^n|NC, IM_m)\, p(NC|IM_m) + P(DV^n|C)\, p(C|IM_m)$$

Loss Analysis: Loss function for collapse

$$P(DV^n|NC, IM_m) = \sum_j P(DV_j^n|NC, IM_m)$$

Structural Analysis

$$P(DV_j^n|NC, IM_m) = \sum_i P(DV_j^n|EDP_j^i)\, p(EDP_j^i|IM_m)$$

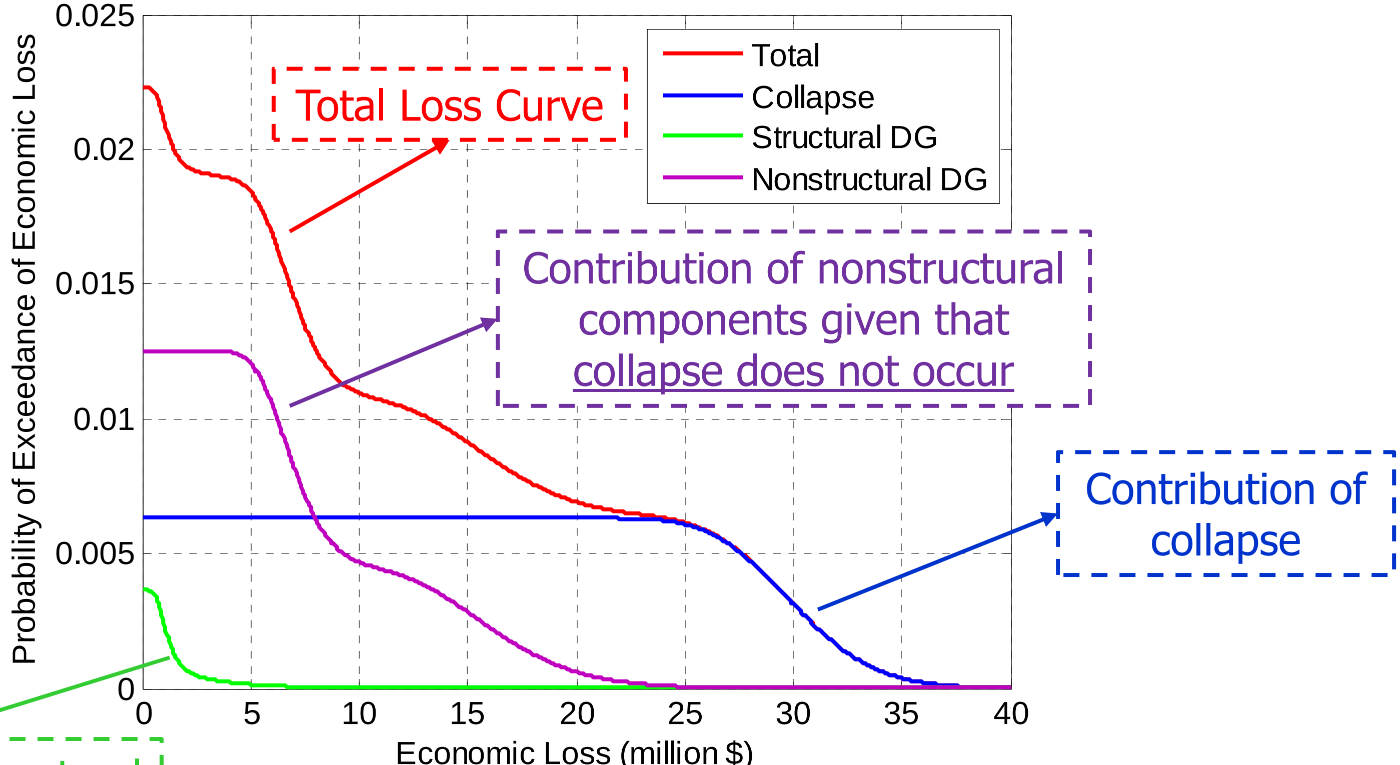
$$P(DV_j^n|EDP_j^i) = \sum_k P(DV_j^n|DM_k)\, p(DM_k|EDP_j^i)$$

Loss Analysis — **Damage Analysis**

- **m: index for IM**
- **j: index for damageable groups (DG)**
- **i: index for EDP**
- **k: index for DM**

Application III

Combination of Analyses: Loss Curve

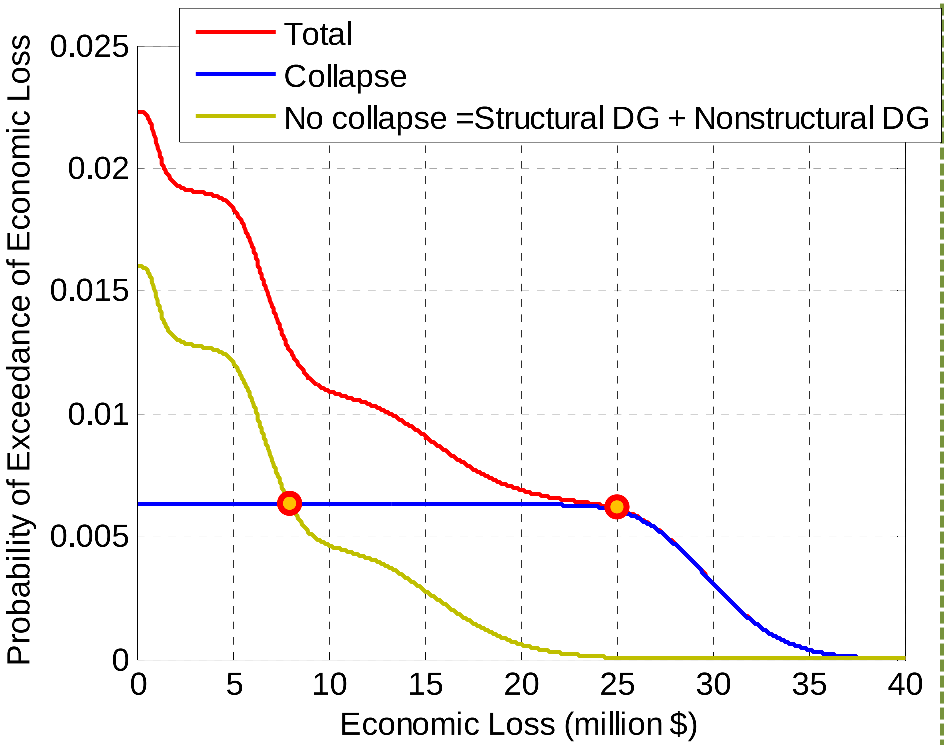


Contribution of structural components given that collapse does not occur

Nonstructural components significantly contribute to loss

Application III

Combination of Analyses: Loss Curve



- No collapse case is more dominant on the total loss curve for monetary losses **less than $8 million**
- All the loss is attributed to the collapse case for monetary losses **greater than $25 million**
- No collapse plot can be interpreted as the loss curve for a hypothetical case where collapse is prevented for all intensity levels
- The significant reduction of economic loss as a result of the elimination of collapse shows the effect of the collapse prevention mandated by the seismic codes from an economical perspective

Application II

Evaluation of the Seismic Response of Structural Insulated Panels with Probabilistic PBEE (in progress)

Application II

Recall
HS Symposium
(Two days ago!)

Application II

HS Symposium (Two days ago): Test Matrix

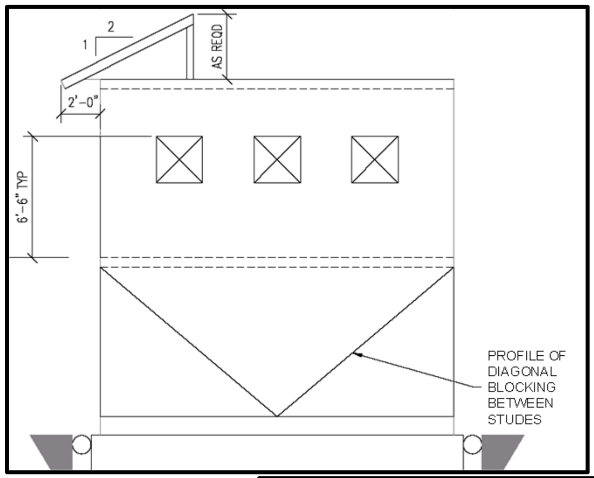
Specimen	Protocol	Gravity	Nail spacing [in]	Remarks
S1	CUREE	No	6	Conventional wood panel
S2	CUREE	No	6	-
S3	CUREE	Yes	6	-
S4	HS	Yes	6	Near-fault pulse-type GM
S5	HS	Yes	3	Near-fault pulse-type GM
S6	CUREE	Yes	3	-
S7	HS	Yes	3	Long duration, harmonic GM
S8	HS	Yes	3	Near-fault GM; 3 stories computational substructure

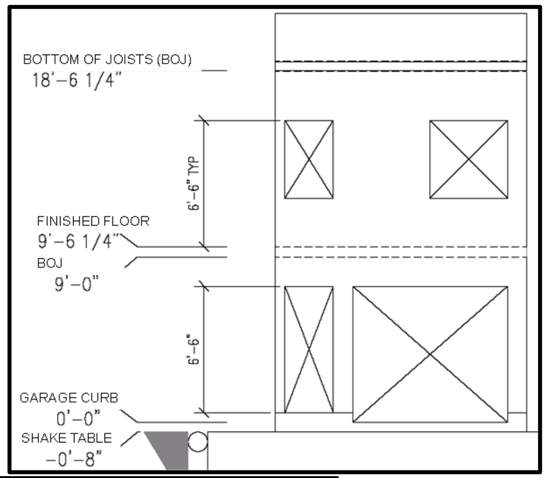
1. Compare the responses of conventional wood panel vs SIPs
2. Investigate the effects of

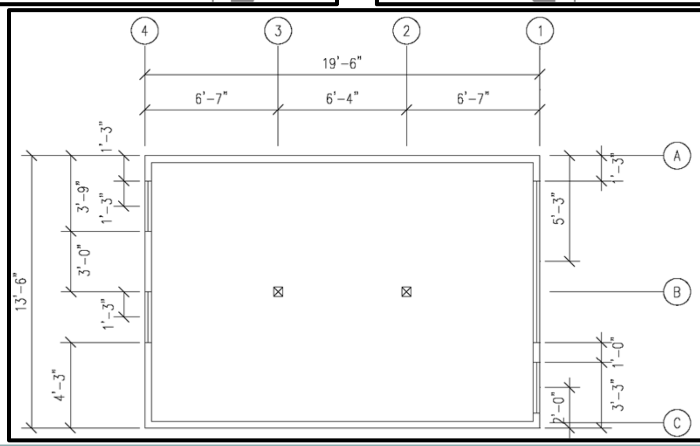
- A parameter related to the design and construction of panels: **Nail spacing**
- Parameters related to loading:
  - ✓ Presence of gravity loading
  - ✓ Lateral loading: *CUREE protocol vs HS*
  - ✓ Type of ground motion (Pulse type vs Long duration, harmonic)
- A parameter related to HS: *Presence of an analytical substructure*

Application II

Objective: Make use of the tests for the performance evaluation of a 3D structure using PEER PBEE methodology





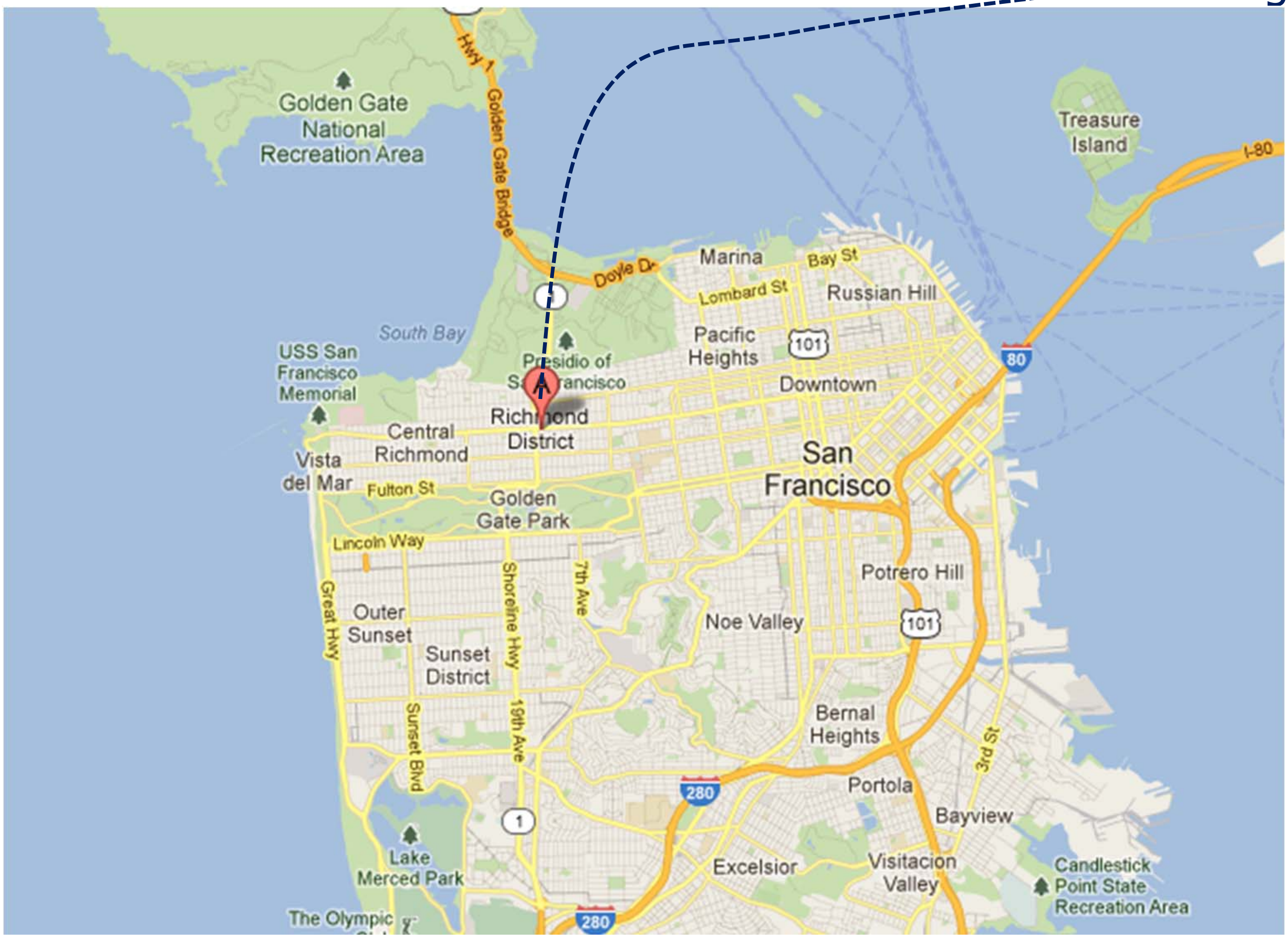


1940's San Francisco house-over-garage tested at UC-Berkeley [Mosalam et al., 2009]

Application II

Hazard Analysis

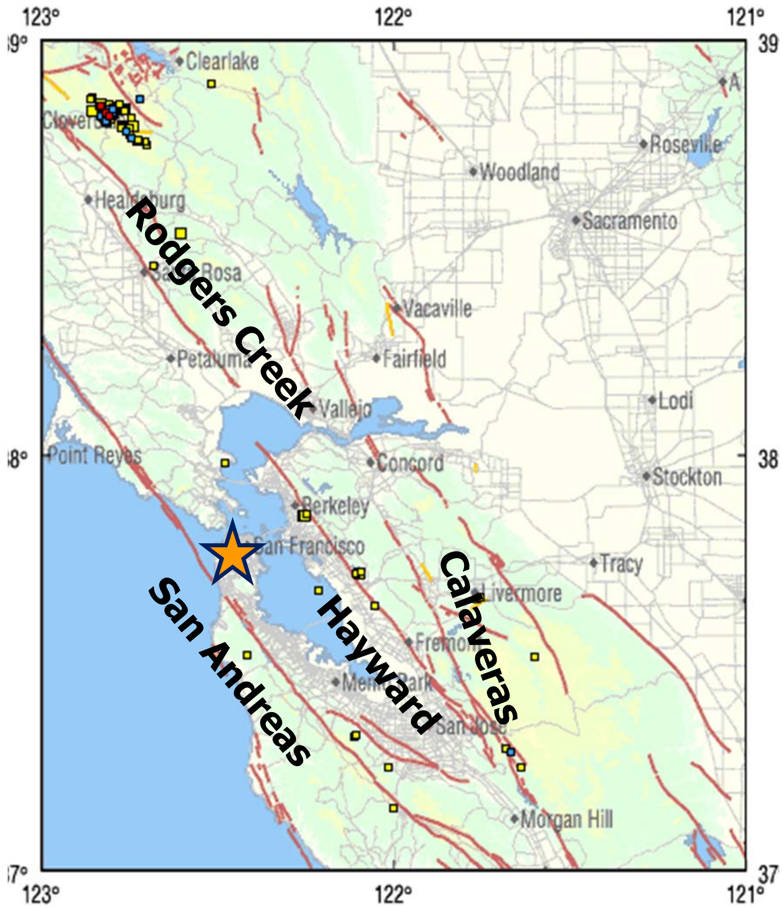
Location of a house over garage in San Francisco



Site class: NEHRP D

Application II

Hazard Analysis

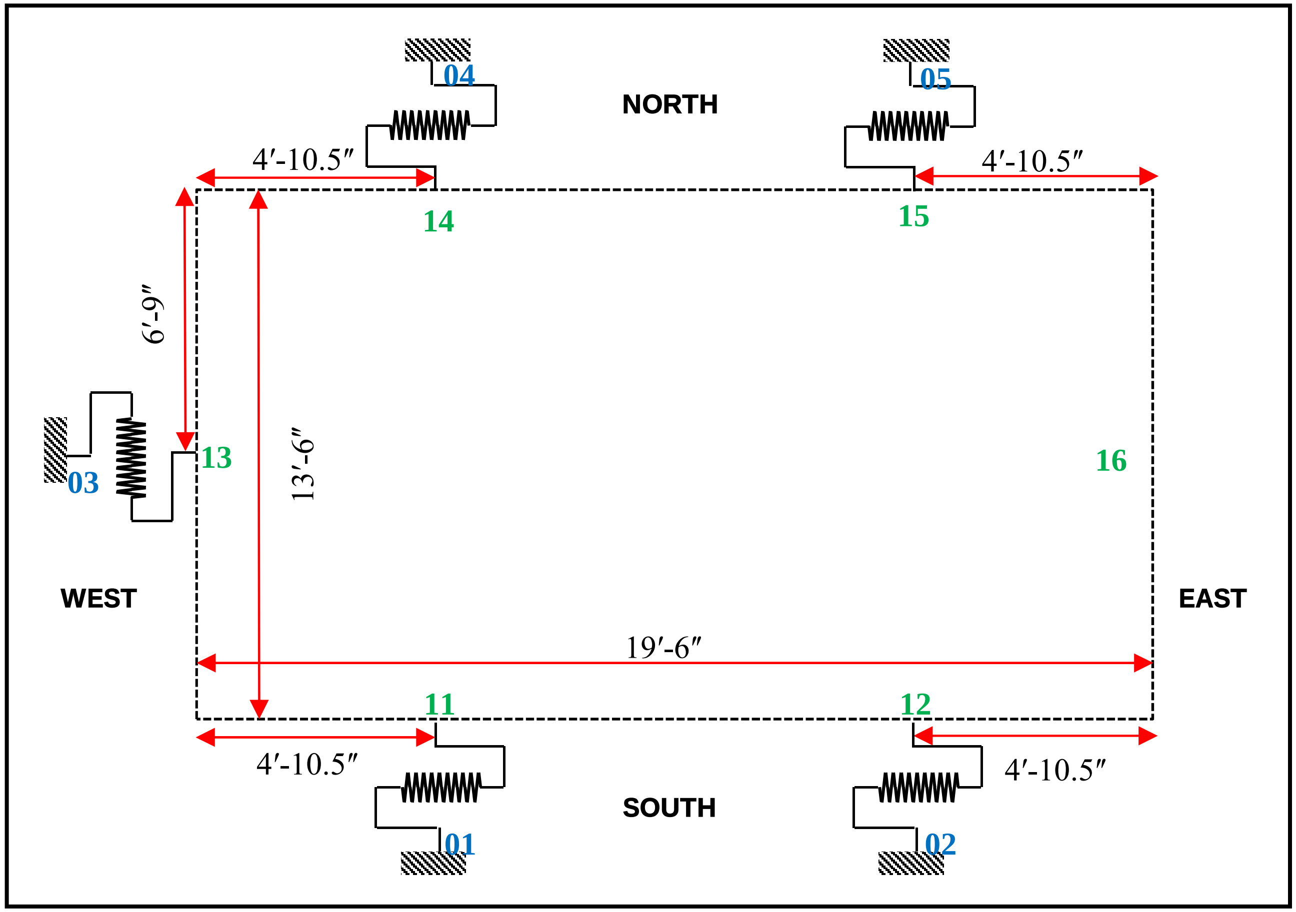


Source: USGS

Application II

Structural Analysis

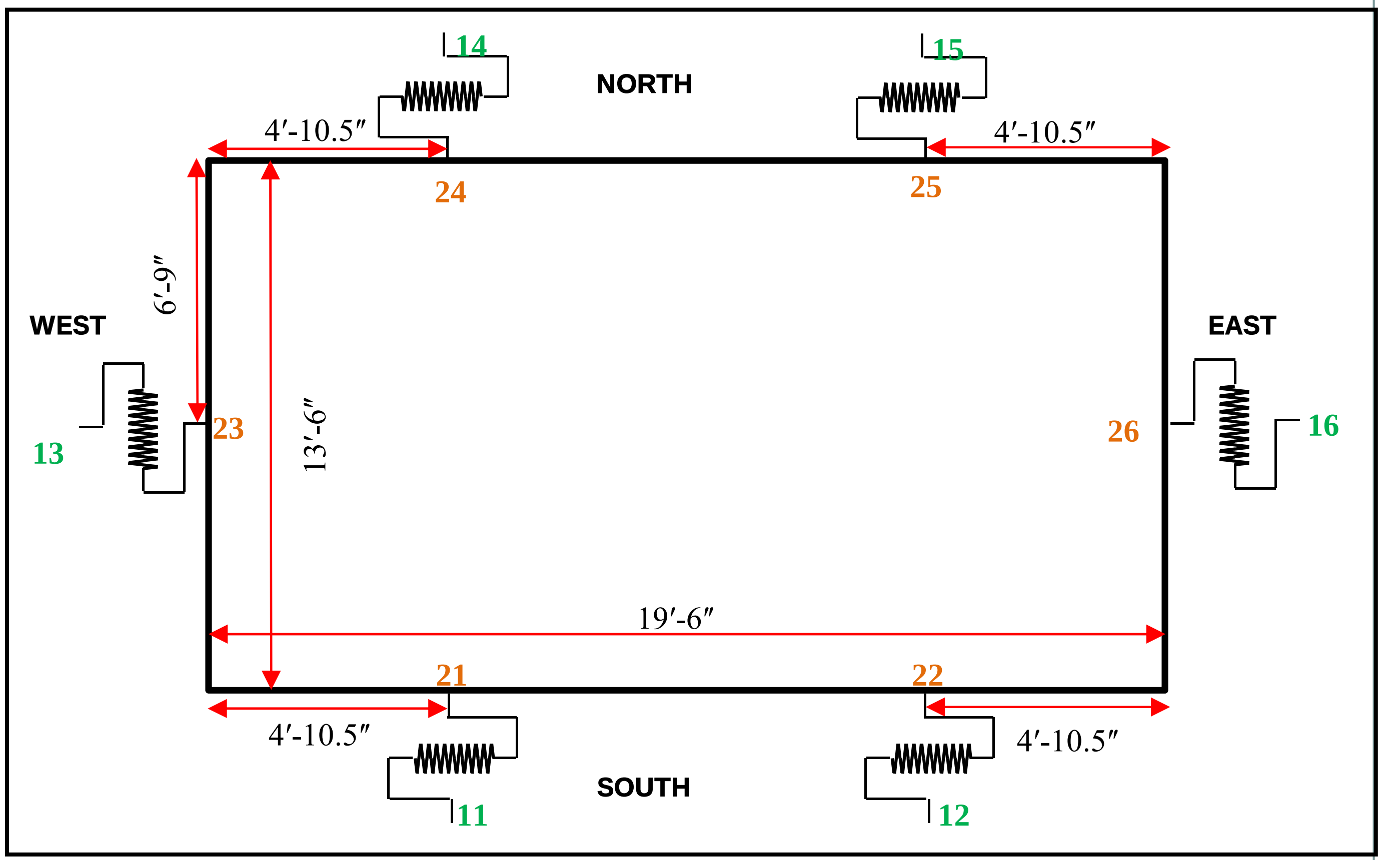
Level 1 Plan View



Application II

Structural Analysis

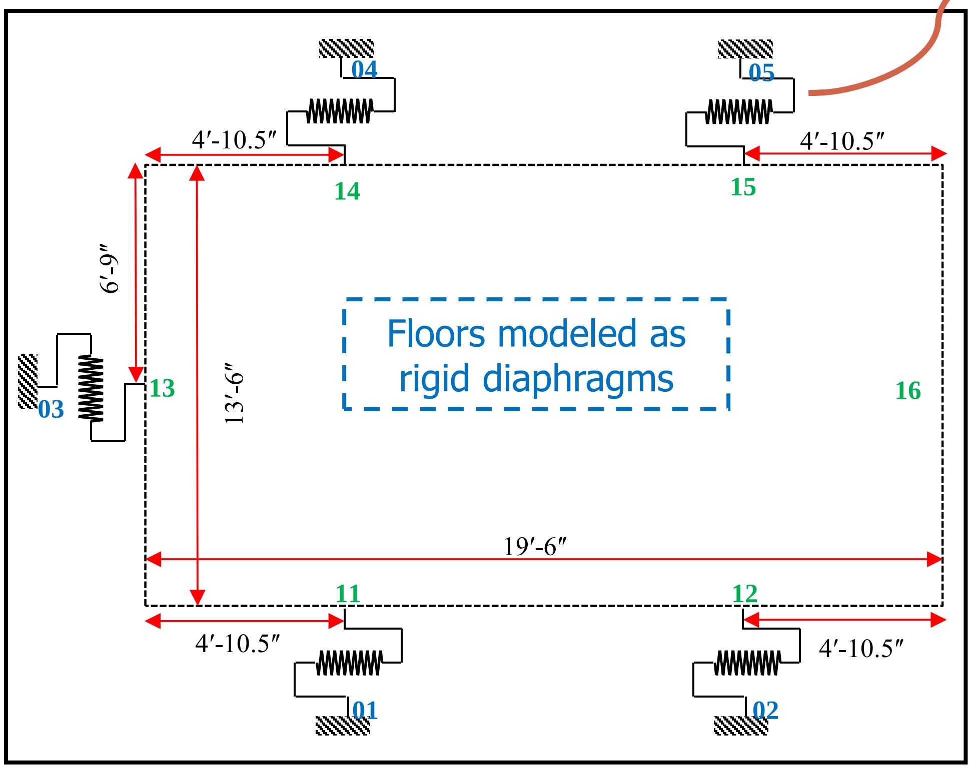
Level 2 Plan View



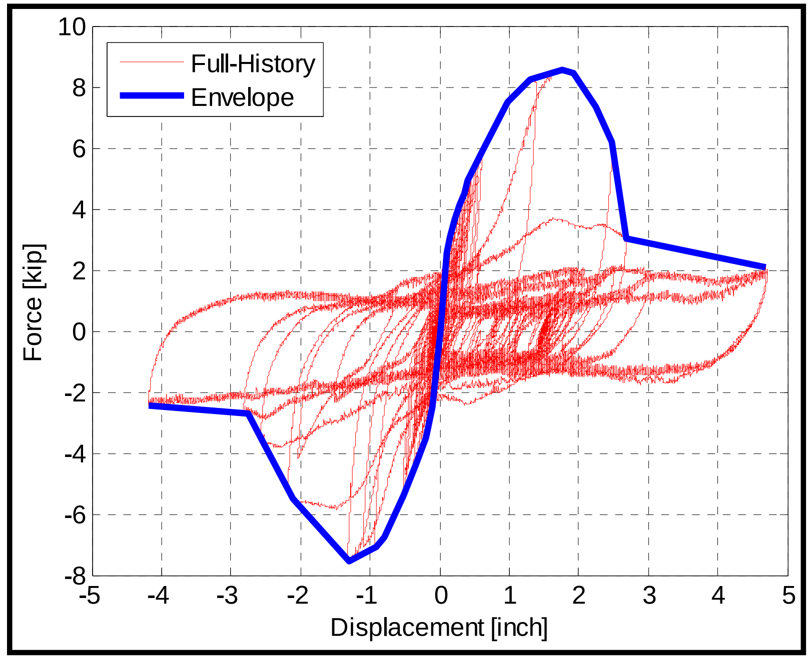
Application II

Structural Analysis

Level 1 Plan View



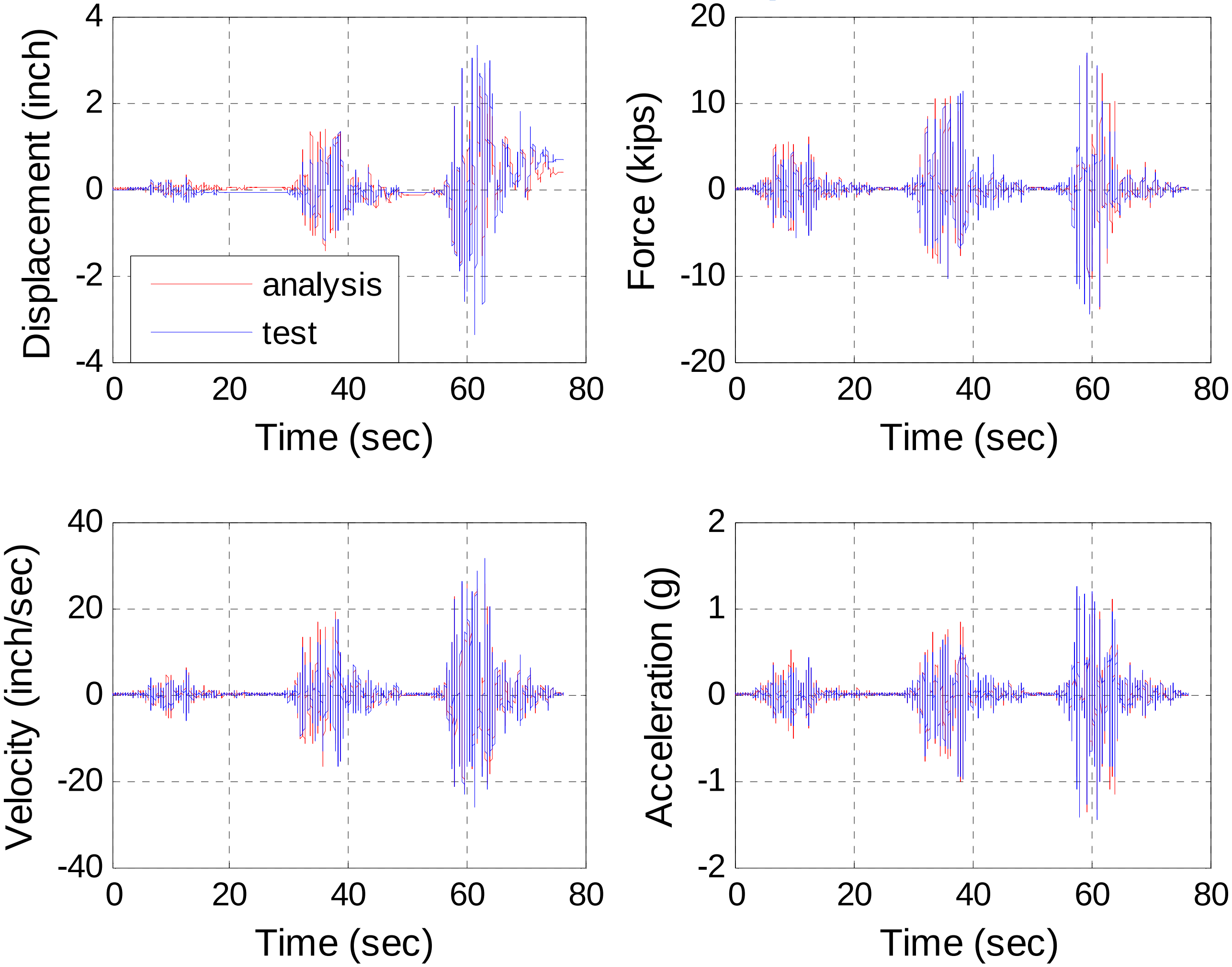
- ❑ Envelope of the force deformation relationship of the springs obtained from the tests



- ❑ Parameters used to define the hysteretic relationship is calibrated by the analysis (next slide)

Application II

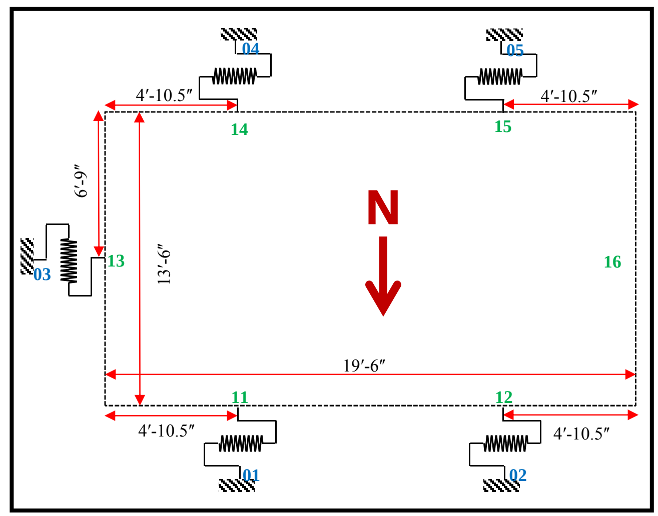
Structural Analysis



Application II

Structural Analysis

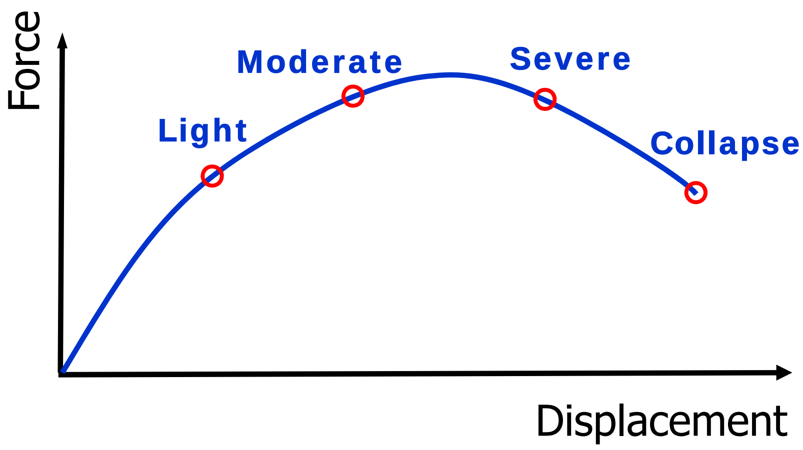
- 3182 ground motions from the recent version of PEER NGA database
  http://peer.berkeley.edu/peer_ground_motion_database/
- Unscaled ground motions
- Ground motions seperated into bins based on $Sa(T_1)$
- T_1 is the period in the north south direction which is the critical mode because of torsional coupling
- Nonlinear time history analyses using the 3182 ground motions for each analytical model corresponding to a specimen
- **EDP**: Maximum Interstory Drift (MIDR)



Application II

Damage Analysis

- Conduct pushover analysis for each analytical model corresponding to a different specimen
- Determine the damage levels on each pushover curve
- Obtain MIDR values at the pushover steps corresponding to the determined damage levels for each analytical model
- Determine the median and coefficient of variation of MIDR for each damage level from the values obtained from each analytical model



Application II

Loss Analysis

- Determine the median value of loss corresponding to each damage level as a percentage of total value of the building

- Determine the corresponding coefficient of variation

- Obtain the loss curves from a probabilistic distribution

Thank you