Pacific Earthquake Engineering Research Center

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Berkeley, California

"High Fidelity" Nonlinear Building Simulation and Use of Open Science Grid

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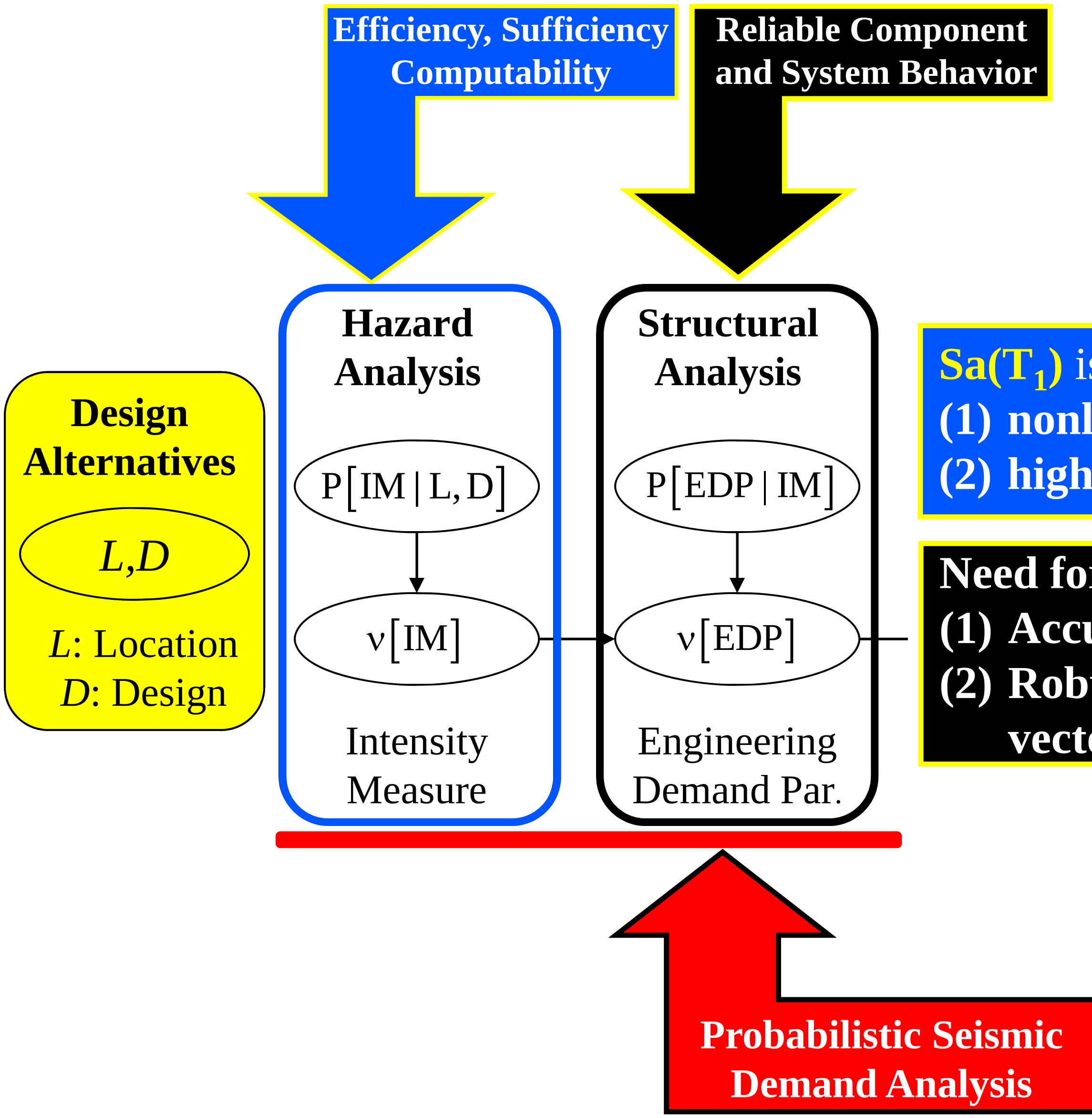
UCSD Jacobs | Structural Engineering

Outline

- **Introduction and Motivation**
- **3-D Modeling of the National Earthquake Hazards Reduction Program (NEHRP) RC Frame-Wall Building**
- **Formulation for Vector-valued Probabilistic Seismic Demand Analysis of 3-D Structural Models**
- **Running OpenSees on Open Science Grid (Application Examples)**
  - Probabilistic seismic demand hazard analysis making use of the “cloud method”
  - Sensitivity of probabilistic seismic demand hazard to finite element (FE) model parameters

PEER PBEE Methodology



$Sa(T_1)$ is **not efficient nor sufficient**:

(1) nonlinear analysis of 3-D structures

(2) higher mode effects

Need for:

(1) Accurate nonlinear FE models

(2) Robust procedures to account for vector-valued IM

PART I

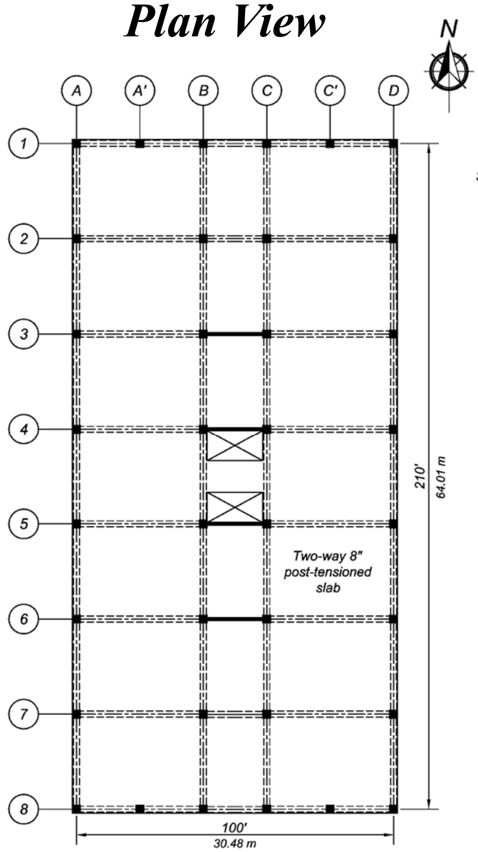
3-D Modeling of the 13-Story NEHRP Building

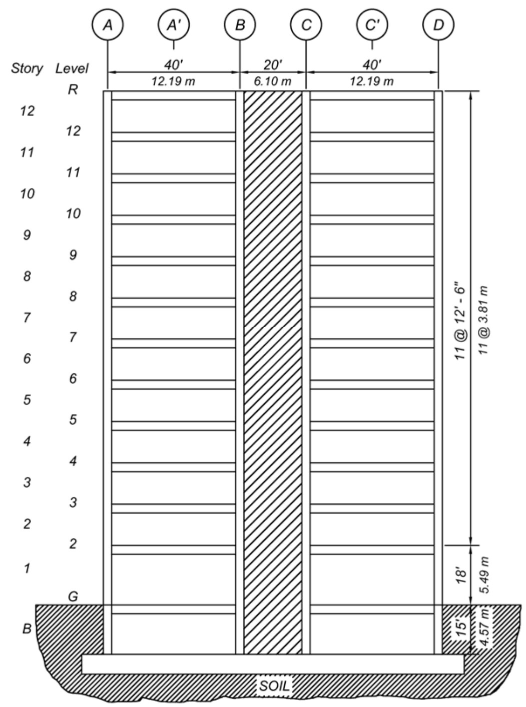
NEHRP R/C Building Example

❑ NEHRP design example (FEMA 451)

- ➢ Demonstrate the design procedures (ASCE7-05, ACI318-08)
- ➢ Building was **re-designed** to account for latest Seismic Design Maps and common practices in California

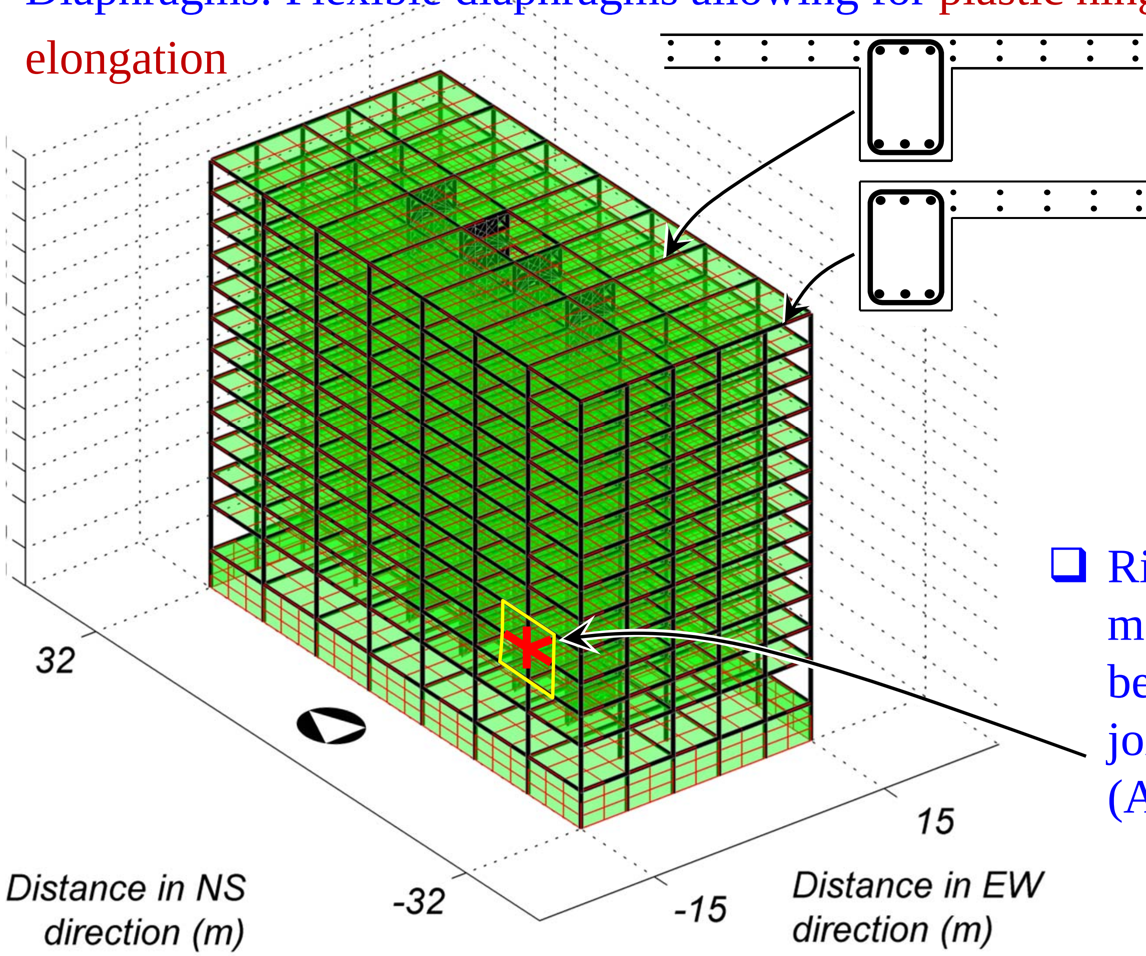
Plan View ***Elevation*** ***Location***

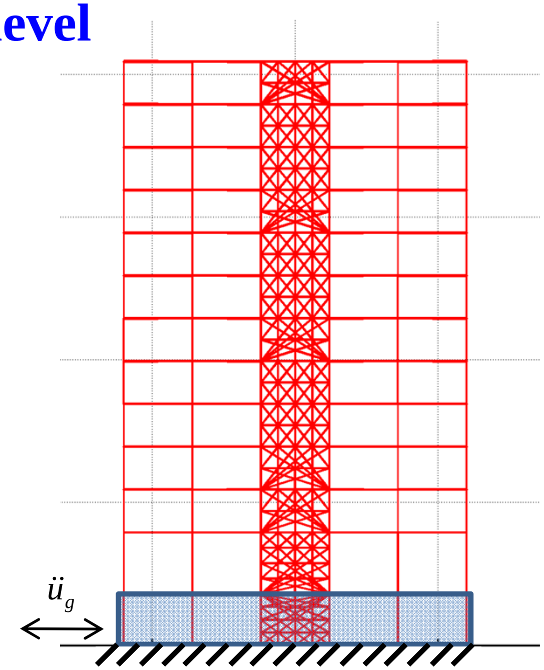




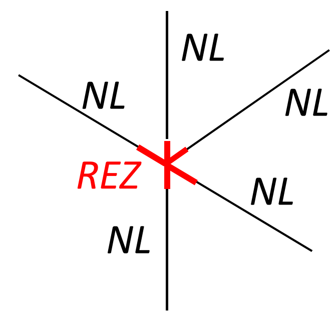
Modeling Approach

- ❑ **Should be comprehensive/significant validation at system level …**
- ❑ **Comprehensive and significant validation at component level**
  - ➢ Walls: Nonlinear truss modeling approach
  - ➢ Columns and beams: Force-based beam-column elements
  - ➢ Diaphragms: Flexible diaphragms allowing for plastic hinge elongation

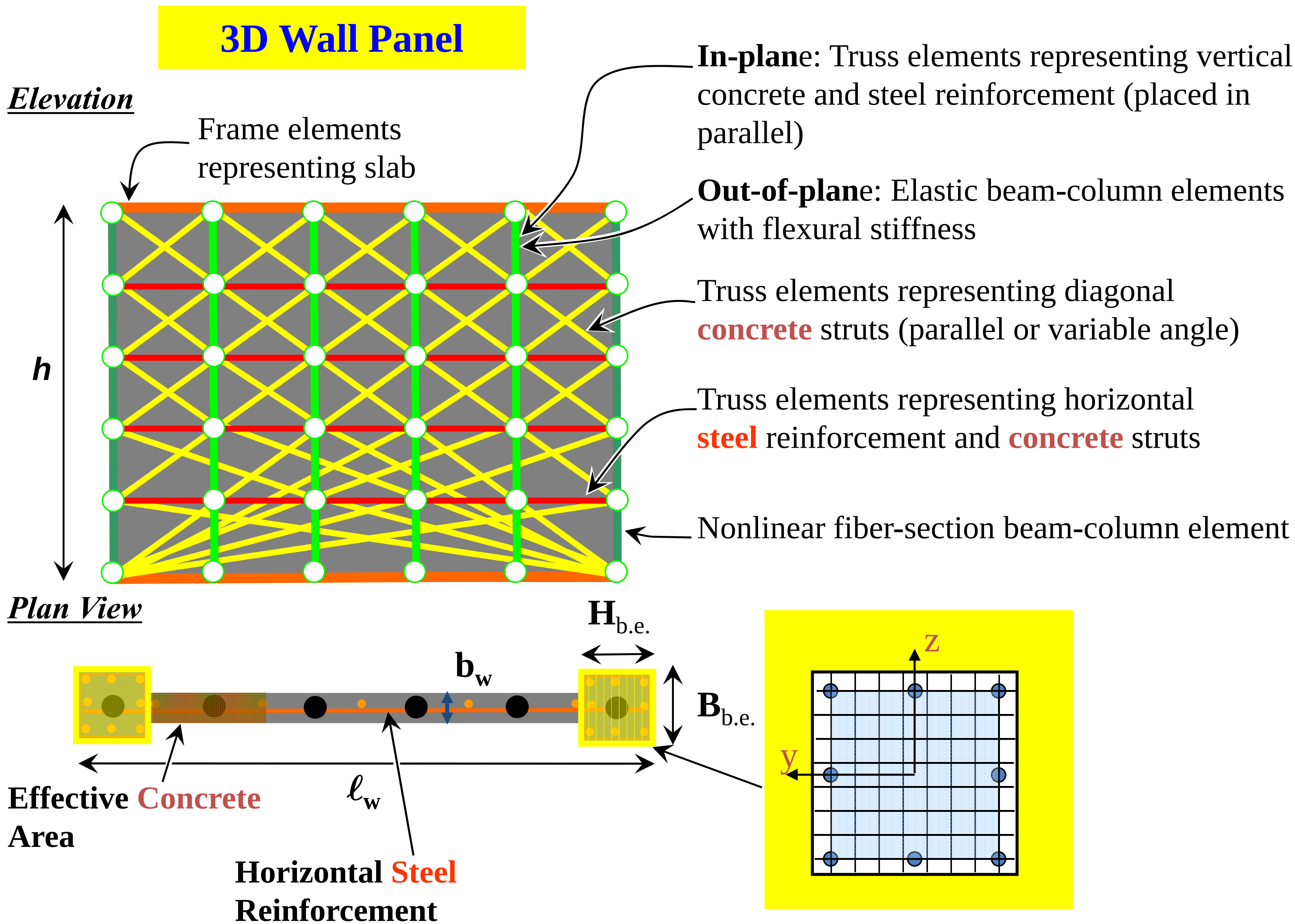




- ❑ Rigid-end zone modeling for beam-column joints (ASCE41-06)



Nonlinear Truss Model for RC Walls



Example of Component Validation: RC Wall

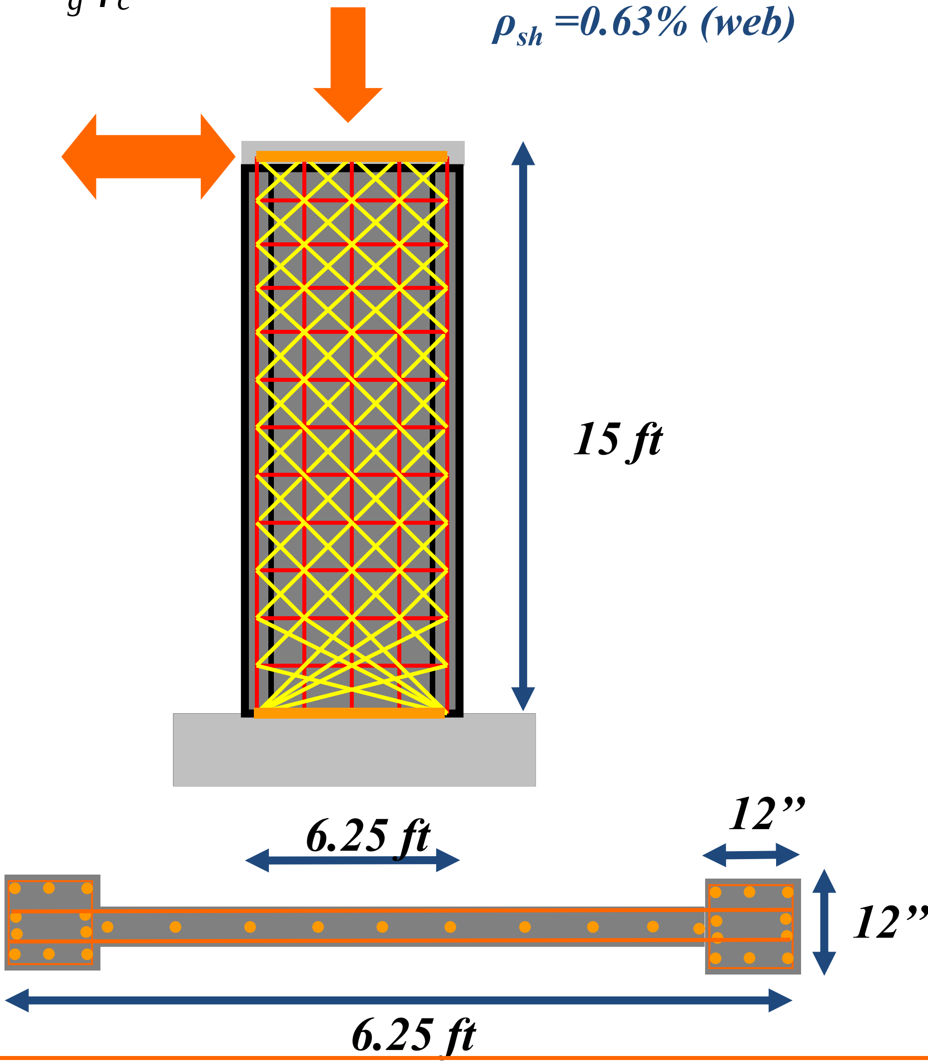
$$\frac{P}{A_g f_c'} = 0.08$$

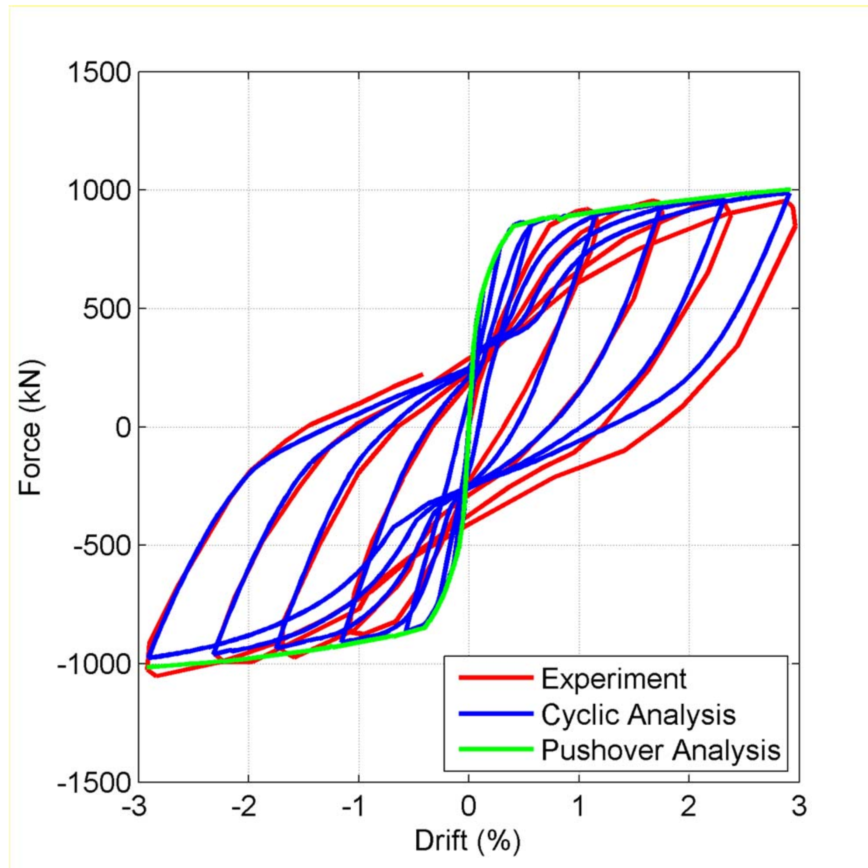
ρ_l=3.67% (boundary elem.)

ρ_l=0.29% (web)

ρ_{sh} =0.63% (web)

Oesterle Test (B7) -1979

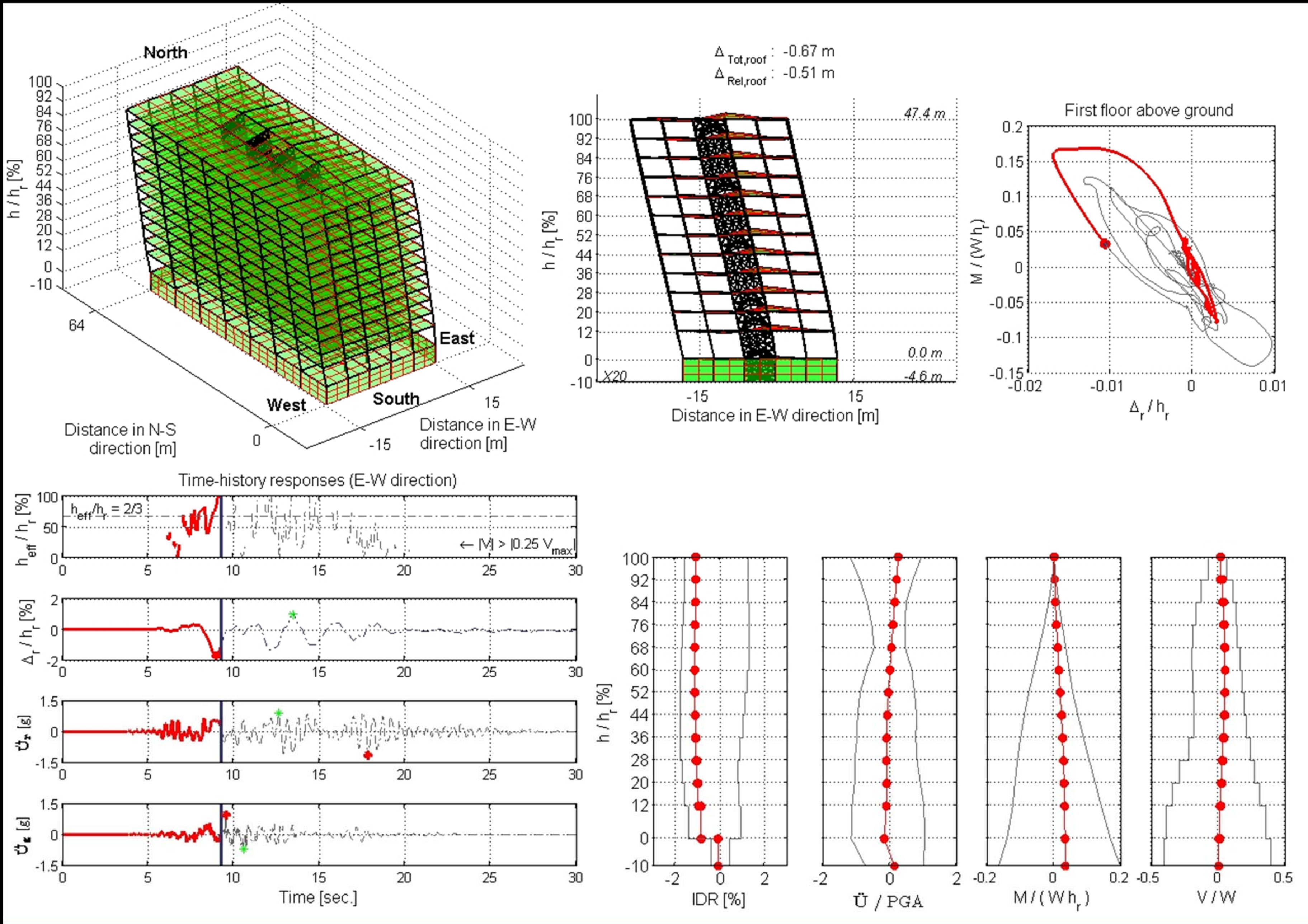




OpenSees: *Concrete02*, *Steel02*

VIDEO

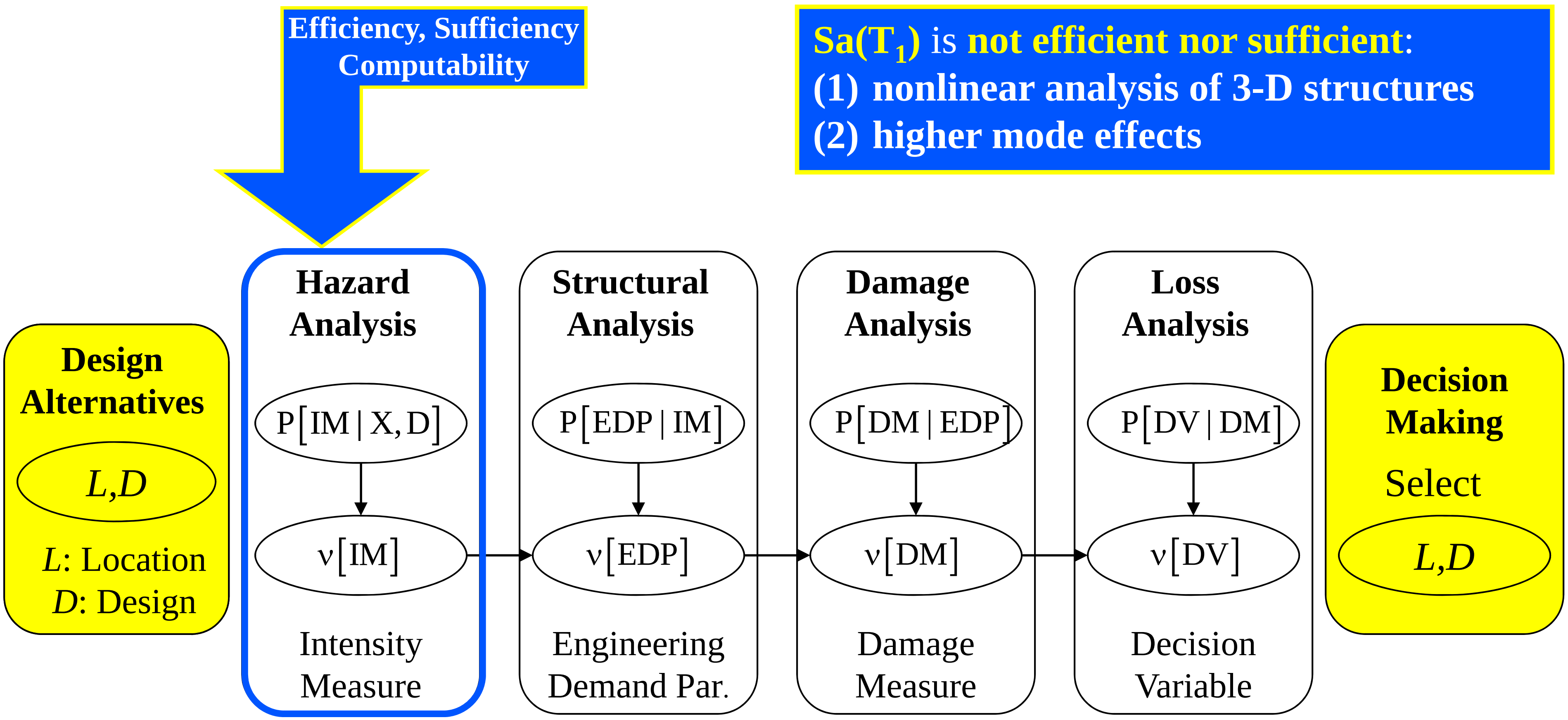
NEHRP BUILDING E-W RESPONSE: LGPC



PART II

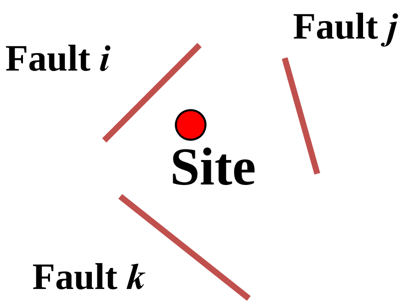
Probabilistic Seismic Demand Analysis for 3-D Structural Models

PEER PBEE Methodology

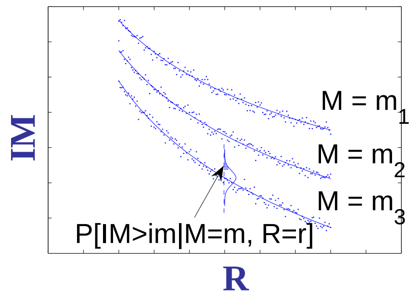


Probabilistic Seismic Hazard Analysis (1)

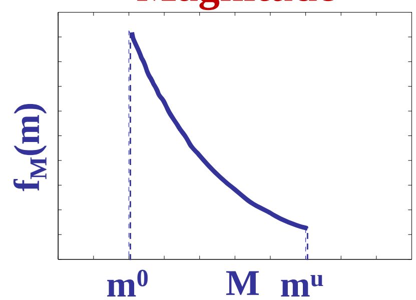
$$\nu_{IM}(im) = \sum_{i=1}^{N_{flt}} \nu_i \int_{R_i} \int_{M_i} P\left[IM > im \mid M_i = m, R_i = r \right] f_{M_i}(m)\, f_{R_i}(r)\, dm\, dr$$



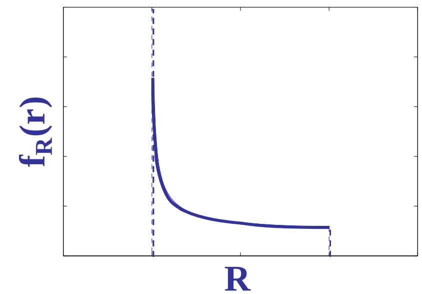
Attenuation relations



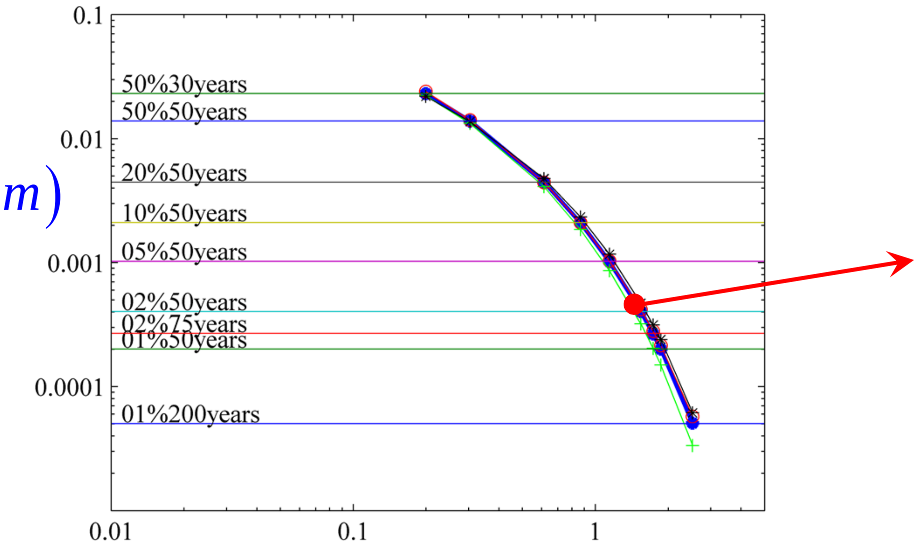
Magnitude



Source-to-site distance



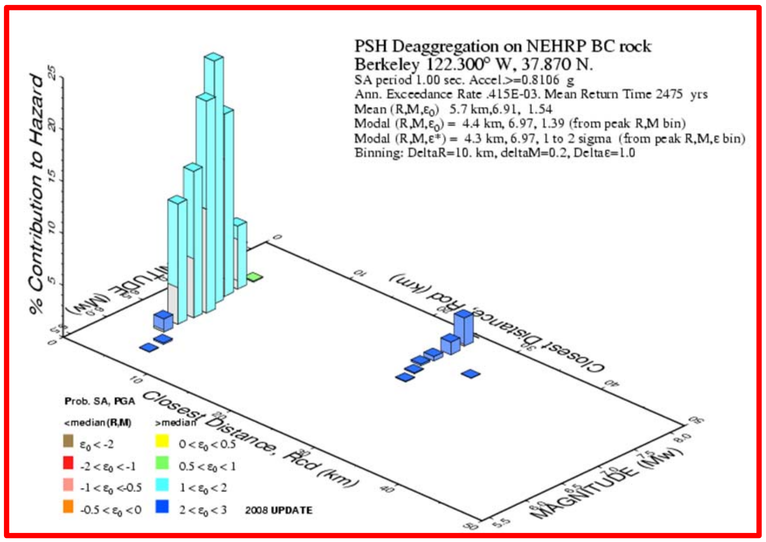
Seismic hazard curve



$\nu_{IM}(im)$

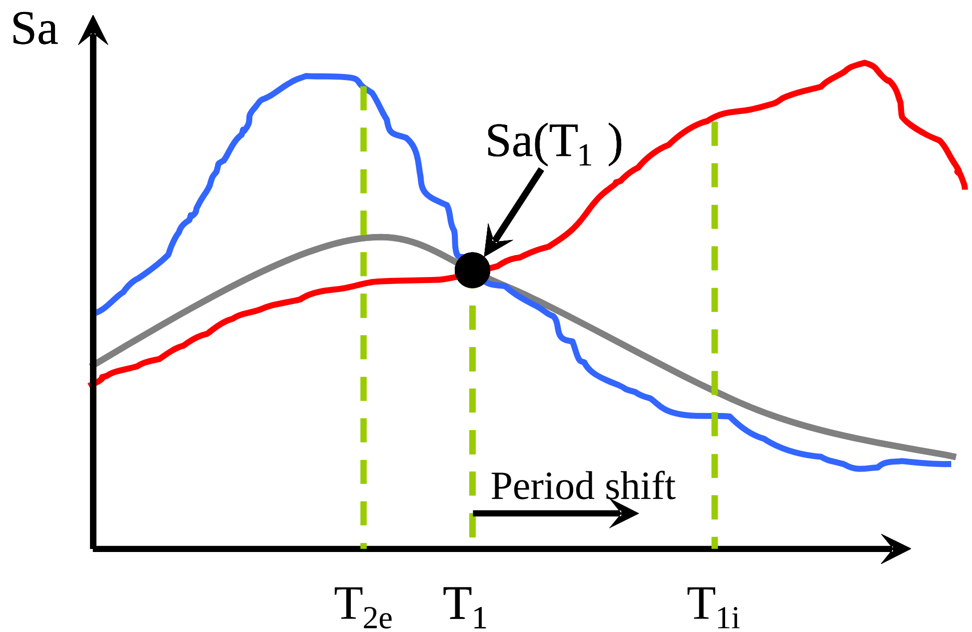
$\mathrm{IM} = \mathrm{Sa}(\mathrm{T}_1)$

M-R deaggregation



Selection of an Intensity Measure (IM)

- **Sa(T_1)** alone as the IM **is not optimal** (e.g. not efficient nor sufficient) in characterizing the ground motion intensity (e.g., for 2-D analysis: Baker and Cornell 2005; Luco and Cornell 2007; for 3-D analysis Faggella et al., 2011)



- Consideration the spectral ordinates at other periods (i.e., proxy for **spectral shape**), namely:
  - due to period lengthening (**inelastic response**)
  - **higher-mode effects**

Vector-valued Probabilistic Seismic Demand Analysis

- Probabilistic seismic demand hazard equation:

$$\nu_{EDP}(edp) = \int_{\mathbf{IM}} P[EDP > edp \mid \mathbf{IM}] \cdot |d\nu_{\mathbf{IM}}(\mathbf{im})|$$

Bazzurro, 1998

- Simplified **VPSHA**
  - **USGS probabilistic seismic hazard results**
  - Latest **NGA ground motion (GM) prediction models**
  - Correlation by **Baker and Jayaram (2008)** for the NGA GM models

$$\nu_{EDP}(edp) = \sum_{all\ x_{1,i}} \sum_{all\ x_{2,j}} P\left[EDP > edp \mid Sa_1 = sa_{1,i}, Sa_2 = sa_{2,j}\right] \cdot P\left[Sa_2 = sa_{2,j} \middle| Sa_1 = sa_{1,i}\right] \cdot \left|\Delta \nu_{Sa_1}(sa_{1,i})\right|$$

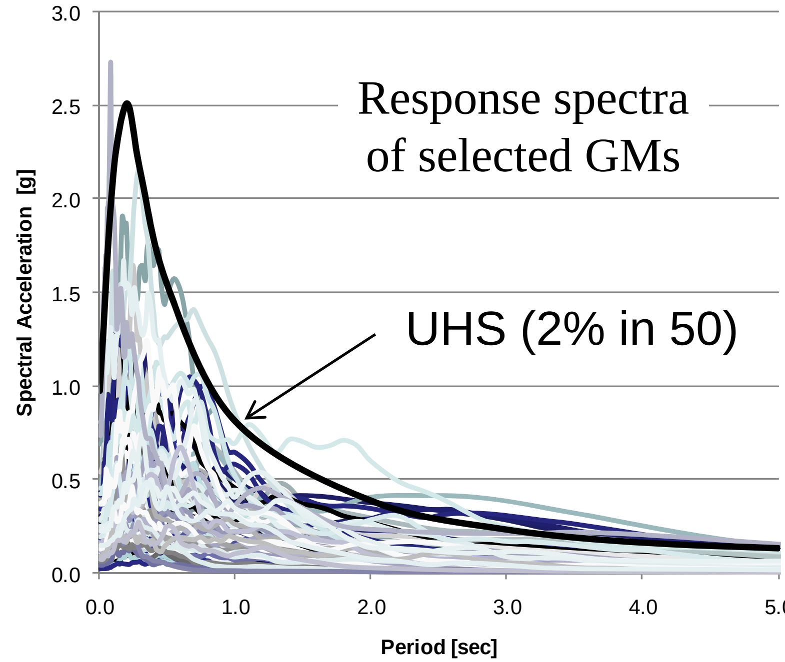
- The second term in hazard analysis is computed for each $sa_{1,i}$ and $sa_{2,j}$:

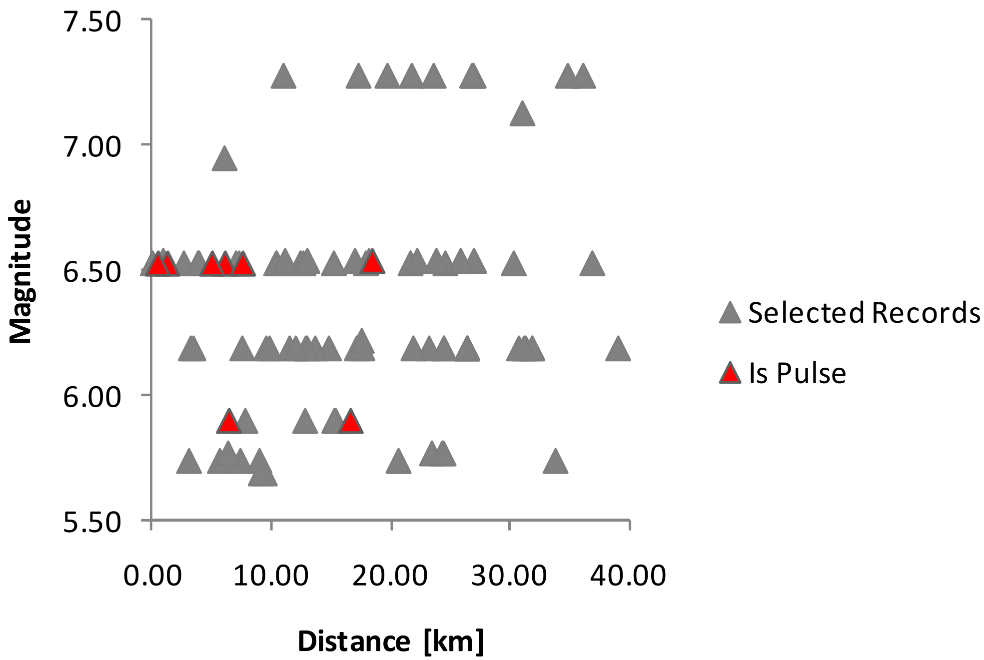
$$P\left[Sa_2 = sa_{2,j} \middle| Sa_1 = sa_{1,i}\right] =$$

$$= \sum_{k=1}^{N_M} \sum_{n=1}^{N_R} \underbrace{P\left[Sa_2 = sa_{2,j} \middle| Sa_1 = sa_{1,i}, M = m_k, R = r_n\right]}_{\textit{Ground motion prediction equation + correlation coefficient}} \cdot \underbrace{P\left[M = m_k, R = r_n \mid Sa_1 = sa_{1,i}\right]}_{\textit{M and R deaggregation of scalar hazard from USGS}}$$

Earthquake Records

- **NGA database (total 3551 records)**
  - Mechanism: Strike-slip (1004 records)
  - Magnitude range: 5.5 to 8 (772 records)
  - Distance: 0 – 40 kms (203 records)
  - Vs30: C/D range (90 records)
- **90 ground motion records selected from 14 earthquakes**





Distance [km]	Mw	# of records
0-20	5.5-6.4	27
0-20	6.4-7.3	27
20-40	5.5-6.4	21
20-40	6.4-7.3	15

PART III

Running OpenSees on Open Science Grid

OpenSees and Parameters Studies

Motivation

- Perform parametric studies that involve **large-scale nonlinear models** of structure or soil-structure systems with **large number of parameters** and **OpenSees runs**.

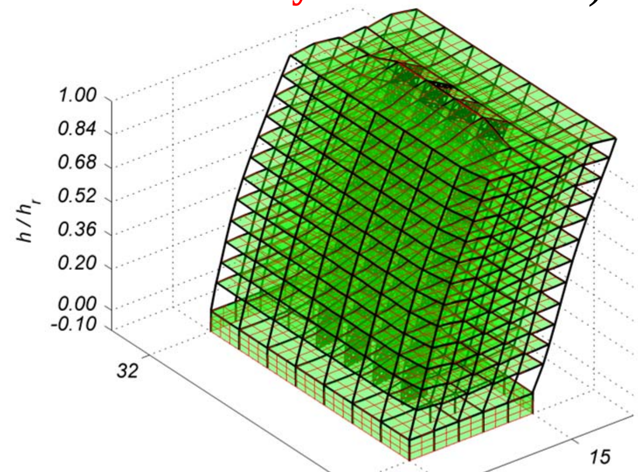
Application example

(1) Probabilistic seismic demand hazard analysis making use of the "cloud method"

- Nonlinear time-history (NLTH) analyses of an advanced nonlinear FE model of a building,
- 90 bi-directional historical earthquake records (**unscaled** and **scaled by a factor of two**)

Some numbers for this application example

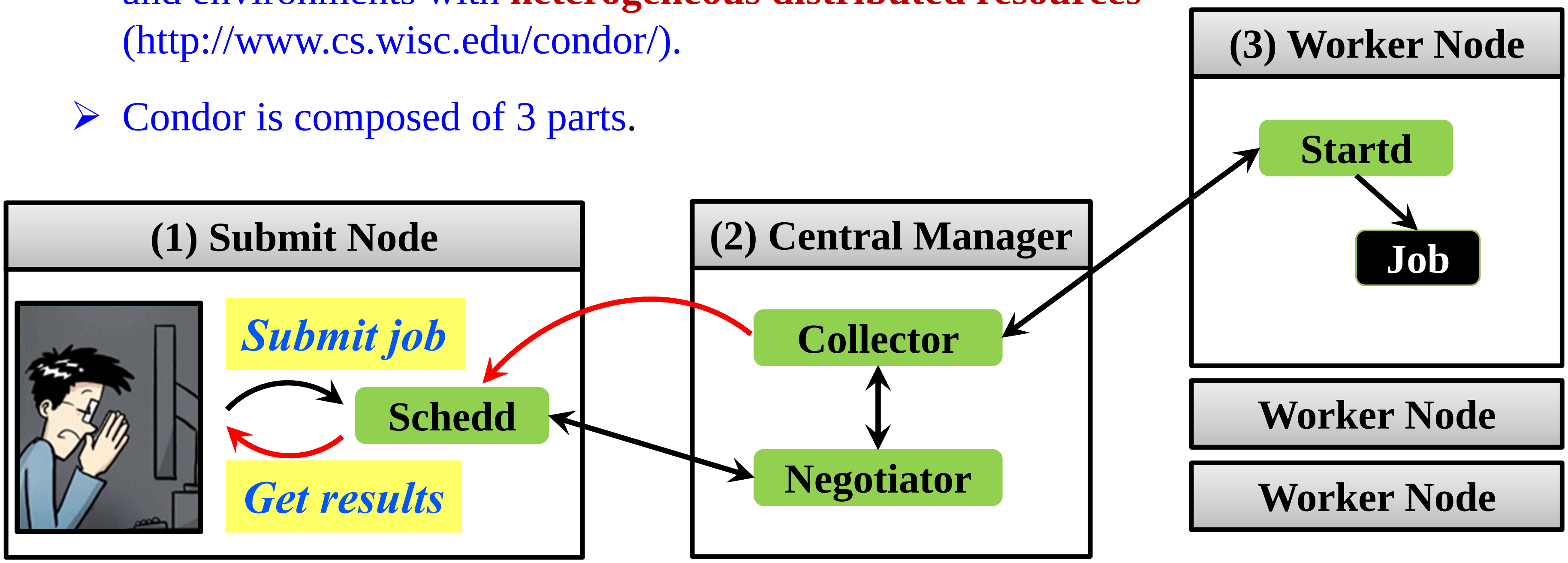
Number of NLTH analyses	180
Average duration of NLTH analysis	12 hours
Average size of output data	1.4 GB
Estimated clock time on a desktop computer (180x12)	**2,160 hours** **90 days**
Estimated size of output data (180x1.4)	**250 GB**



1. Local Cluster?
2. OpenSeesMP + Teragrid?
3. Other options?

Condor and Open Science Grid

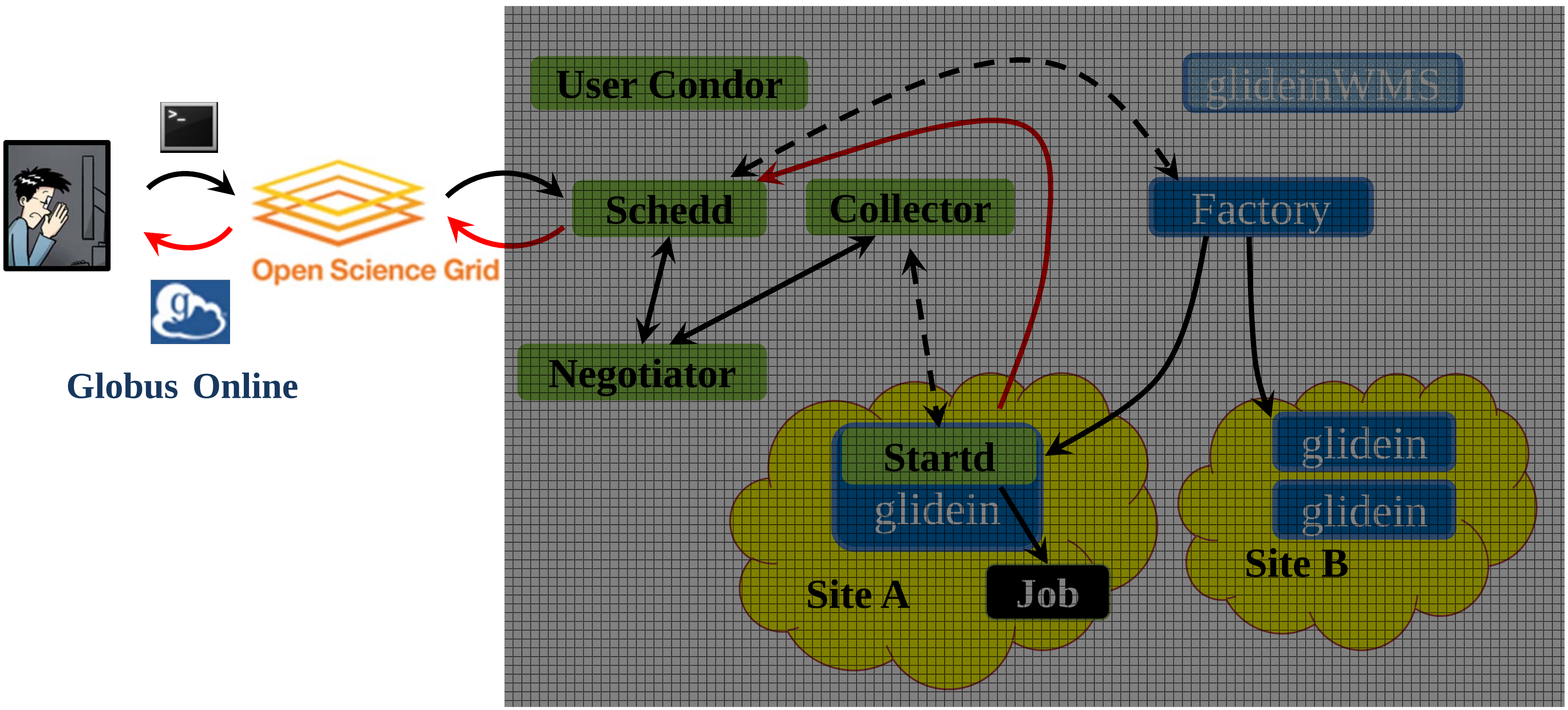
- **Condor** is a specialized workload management system for computational-intensive jobs.
  - Project started in 1988, directed at users with **large computing needs** and environments with **heterogeneous distributed resources** (http://www.cs.wisc.edu/condor/).
  - Condor is composed of 3 parts.



- **Open Science Grid** is a national, distributed computing grid for data-intensive research.
  - Consortium of approx. **80 national laboratories and universities**.
  - **Opportunistic resource usage:** resources are sized for peak needs of large experiments (Atlas, CMS, etc.), OSG allows for non-paying VO organizations to use their resources.
  - Version of Condor for the grid

Using Open Science Grid

- Some sites at **Open Science Grid** use the workload management system (glideinWMS) that provides a simple way to access their grid resources



https://twiki.grid.iu.edu/bin/view/Engagement/EngageOpenSeesProductionDemo

OpenSees and Parameters Studies

❑ Motivation

➢ Perform parametric studies that involve large-scale nonlinear models of structure or soil-structure systems with large number of parameters and OpenSees runs.

❑ Application example

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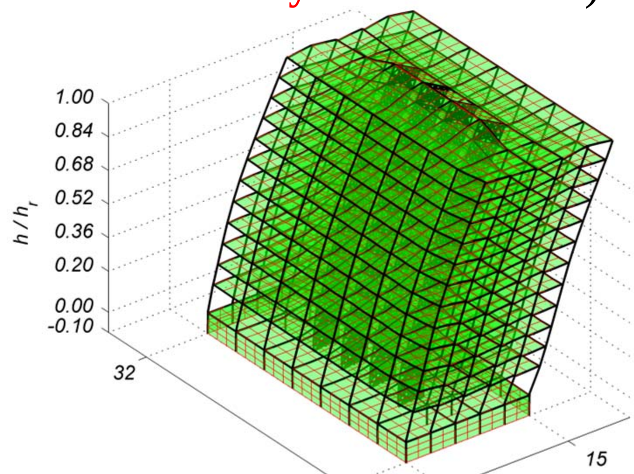


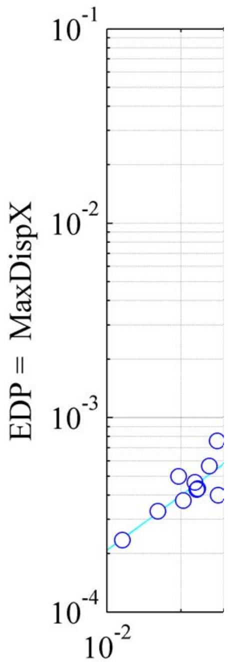
Open Science Grid

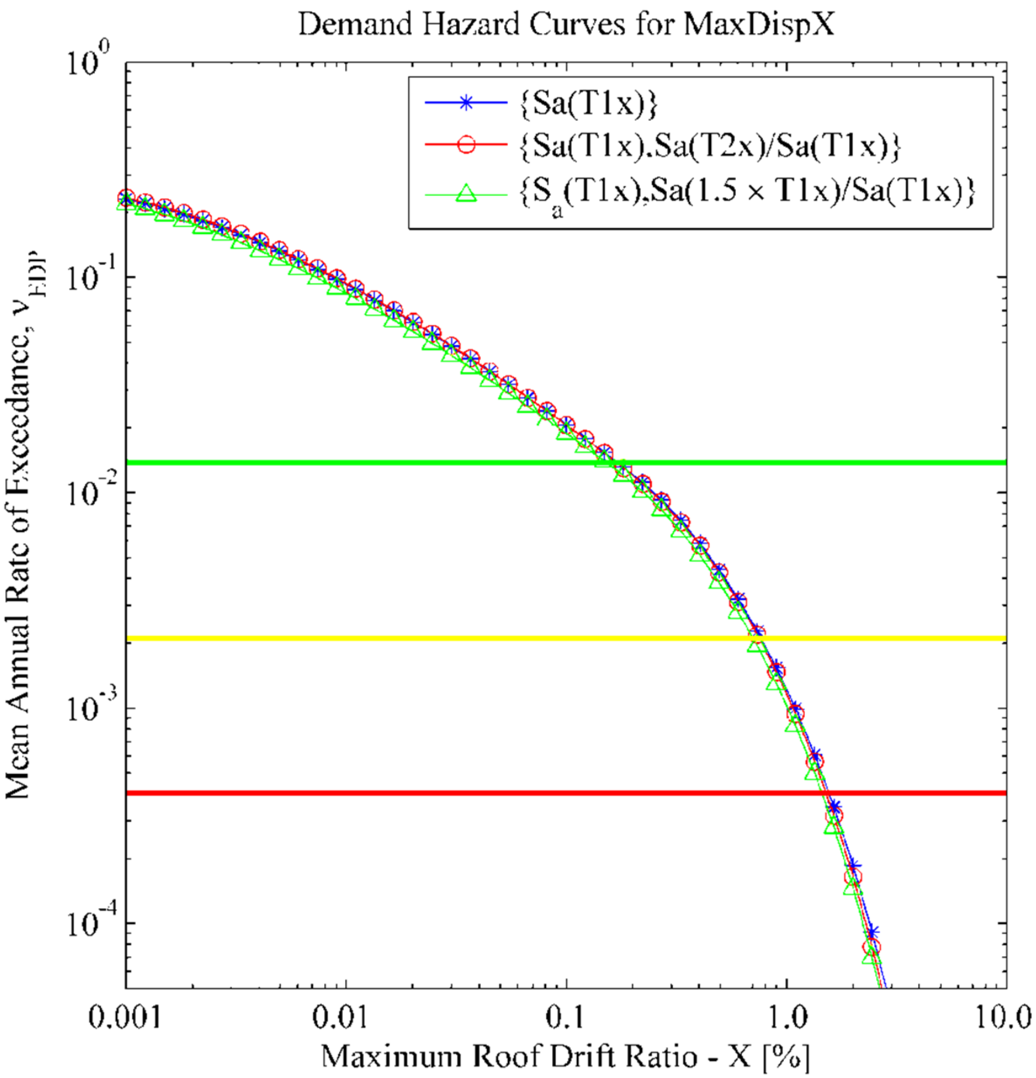
Estimated clock time 24 hours !!

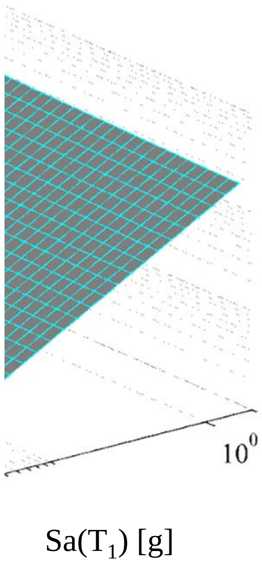
Estimation of the Peak Roof Displacement

R^2=0.904

R^2=0.906

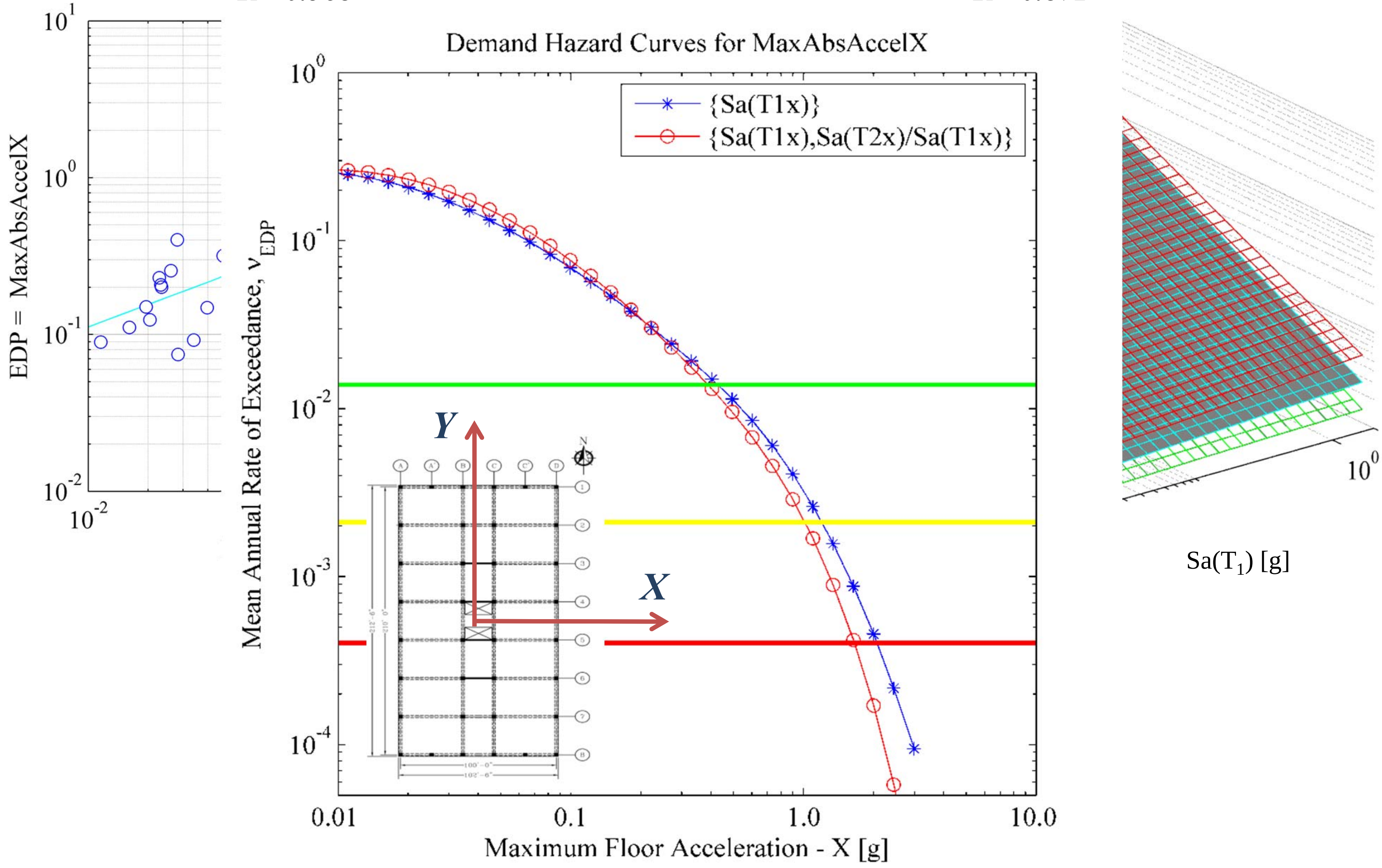






Estimation of the Maximum Peak Absolute Acceleration

R^2=0.568 ***R^2=0.871***



Using Open Science Grid: Application Example 2

Motivation

- Perform parametric studies that involve large-scale nonlinear models of structure or soil-structure systems with large number of parameters and OpenSees runs.

Application example

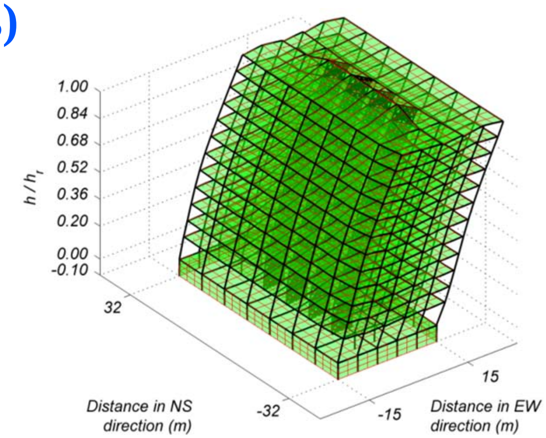
(1) Probabilistic seismic demand hazard analysis making use of the "cloud method"

(2) Sensitivity of probabilistic seismic demand hazard to FE model parameters

- Nonlinear time-history (NLTH) analyses of advanced nonlinear FE model of a building
- 90 bi-directional historical earthquake records (unscaled and scaled by a factor of two)

Some numbers for application example 2 (work in progress)

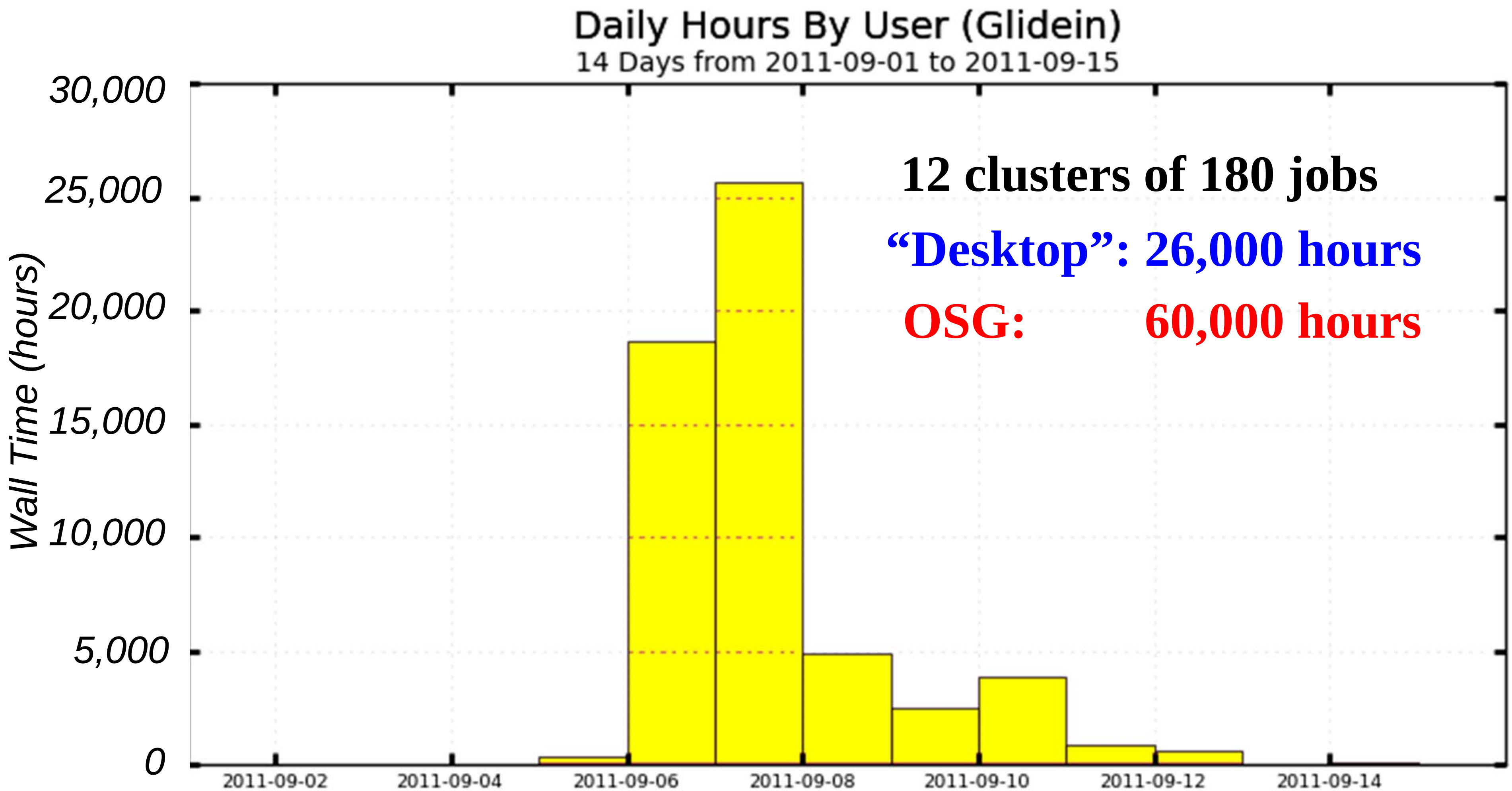
Number of NLTH analyses **per parameter set realization**	180
Average duration of NLTH analysis	12 hours
Average size of output data	1.4 GB
Parameters considered	6
Perturbations considered	4
Estimated clock time on a desktop computer (180x12x[(6x4x2)+1])	**105,840 hours** **12.1 years**
Estimated size of output **(compressed)** data (180x1.4x[(6x4x2)+1])	**12 TB**



Open Science Grid

Estimated clock time 30 days !!

Wall clock time in OSG



OSG users: André R. Barbosa, Taylor Gugino (UCSD)
OSG support: Gabriele Garzoglio, Marko Slyz (OSG)

Conclusions

- **Comprehensive/significant validation of numerical models is required in order to obtain high-fidelity results.**
- **Three-dimensional models have to properly account for adequate modeling of the components and their interaction (between walls, slab and the gravity system).**
- **Probability based tools for seismic demand assessment have been developed, and provide for more accurate and efficient results.**
- **A workflow for running parametric studies that involve large-scale nonlinear models of structure or soil-structure systems with large number of parameters and OpenSees runs on Open Science Grid has been developed and is under testing.**

Challenges…

- ✓ **Comprehensive validation of numerical models for systems**
- ✓ **Opportunistic usage of computational resources**
  - ❑ **How to cope with job recovery (jobs that are stopped because of preemption on OSG) ?**
- ✓ **Management and Analysis of Large Research Data Sets**
  - ❑ **Where and what to store?**
  - ❑ **Data compression algorithms?**
  - ❑ **How to tune data transfers?**
- ✓ **Education: OpenSees + Condor and OSG?**
  - ❑ **User interfaces for submitting jobs, receiving results**
  - ❑ **Data visualization**

Acknowledgements

- **PEER and NEES**
- **Modeling**
  - ➢ Professor Marios Panagiotou (UC Berkeley)
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  - ➢ Dr. Paolo Bazzurro (Air-Worldwide)
  - ➢ Dr. Stephen Harmsen (USGS)
- **Sensitivity of the Probabilistic Seismic Demand Analysis**
  - ➢ Dr. Gabriele Garzoglio, Dr. Marko Slyz (Open Science Grid)
  - ➢ Taylor Gugino (Undergraduate student) (UCSD)

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