Fri-PM SESSION #6: EDPs for Nonstructural Components

Moderator: André Filiatrault
Speakers: Bob Bachman, Eduardo Miranda
Research Committee Contact: Greg Deierlein

Theme statement:
Damage to nonstructural components and building contents are major contributors to earthquake losses. Accurate prediction of nonstructural component and content damage requires probabilistic characterization of appropriate engineering demand parameters, which serve as "input" to component fragility curves. Two obvious first-order demand parameters are inter-story drift and floor accelerations for "deformation sensitive" and "motion sensitive" components, respectively. However, many questions remain on how to best quantify these and other more refined parameters. Deciding the most appropriate demand parameters requires trade offs between precision and practicality, considering realistic levels of uncertainty in quantifying the properties and response of nonstructural components and contents.

Five Discussion Questions: 10 minutes discussion per question

1. What is the short list of most promising Engineering Demand Parameters (EDPs) to quantify performance (damage, loss of functionality, life safety hazards) of nonstructural elements and building contents? Do we have sufficient evidence to limit our research to a definitive "short list", or should PEER devote resources towards studying the choice of EDPs?

- **Using data from nuclear industry**
- **PFA vs spectral acceleration**
- **Input EDP vs response EDP**
- **EDP function of NSC type**

2. Which nonstructural components contribute most to losses, where losses include direct dollar losses, downtime, and injuries/casualties?

- **Better gathering of data to distinguish between damage to different components**
- **ATC 58 has data gathering protocol task**
- **Get "sanitized" information from other communities that already have them**
- **Qualification tests still valuable**
- **International data (e.g. Canada, Taiwan, etc.)**

3. Which important nonstructural components do we know least about? In other words, should PEER devote research efforts to compiling or creating fragility data for nonstructural components? (Note – PEER's previous and current projects on nonstructural include surveys of damaged buildings and tests to develop new data for laboratory equipment and for architectural partition walls).

- **Yes. Fragility curves are needed**
    - **Looking for data**
    - **More experiments**
    - **Post earthquake data**
- **Instrumenting buildings . cost worthy? Or doing more experiments**
- **Model for evaluation of capacity and demand of NSC**

4. To what extent can engineers design structures to significantly (and economically) reduce damage to nonstructural elements and contents by reducing the EDPs imposed by the structure? Or, is it more cost effective to reduce damage by enhancing (toughening) the performance of nonstructural components themselves?

- **Drift sensitive: control drift of the structure**
- **Acceleration sensitive: control in component level**
- **Case by case**
- **Depends on the weight of the component**

5. Recognizing the available time and resources available over the next four years, where can PEER make the biggest impact on performance-based engineering of nonstructural components and contents? This could include research on (1) developing fragility data on specific components, (2) categorizing and accurate means of assessing relevant EDPs, or (3) evaluating the significance and impact on nonstructural components on losses – as measured by appropriate decision variables.

- **From ATC 58 perspective: should demonstrate and apply PBEE methodology from start to finish for a few components**
- **Secondary effects should be studied**

Engineering Demand Parameters (EDPs) For Nonstructural Components

Robert Bachman, S.E.
Consulting Structural Engineer
Sacramento, California

What are Nonstructural Components (NSCs)?

- Architectural, Mechanical and Electrical systems and components which are commonly found in a structure.
- Includes both passive and operating items.
- Comprehensive list of passive items is found in FEMA356
- Building Contents (furniture, equipment, manufactured products, merchandise, etc.)
- Includes all attachments, bracing and anchorage to the primary structural system.
- *The repair and downtime costs associated with damage to nonstructural components are usually well over 50% of the earthquake damage costs in 1 st world countries*.

What are Some Common Performance Goals for Nonstructural Components?

- Damage after a given earthquake is X percent of the replacement value.
- Time to repair after a given earthquake to permit normal operation is X weeks.
- Full functionality is expected during and following a given earthquake.
- No significant leakage of hazardous materials during or following a given earthquake.
- The nonstructural component has retained its position during and following a given earthquake.

What are Engineering Demand Parameters?

- An EDP is a structural demand parameter that can be used as a measure of damage to an individual component.
- Currently they are defined by PEER as response parameters of the structure as opposed as to the response parameter of an individual component.
- Essentially they are currently defined as the *input* demands to which a nonstructural component is to be subjected (similar to the ground motion inputs to a structure although in the PEER world input ground motions are consider Intensity Measures).

What are Engineering Demand Parameters? (Continued)

- Examples of Engineering *Input* Demand Parameters for nonstructural components include:
  * Interstory Drifts and Seismic Joint Relative Displ.
  * Peak accelerations, velocities and displacements
  * 3-D spectral floor accelerations, velocities and displacements or the floor motions themselves
- If the response of the component is highly coupled to the structure, than the EDP could be the input ground motion.
- It seems that there also could be Engineering *Response* Demand Parameter for certain NSCs. Eg. Anchorage Force

Seismic Demands on Nonstructural Components

- Relative Displacements between support points
  - * Vertical points – Drift
    (Hazard dependent .. 2.5 to 3 % max.)
  - * Horizontal points – Seismic Joints / Isolation planes
    (Hazard dependent)
- In-structure accelerations – we normally think in terms of forces for nonstructural components
- In-structure displacements – just like ground motions – we have accelerations, velocities and displacements

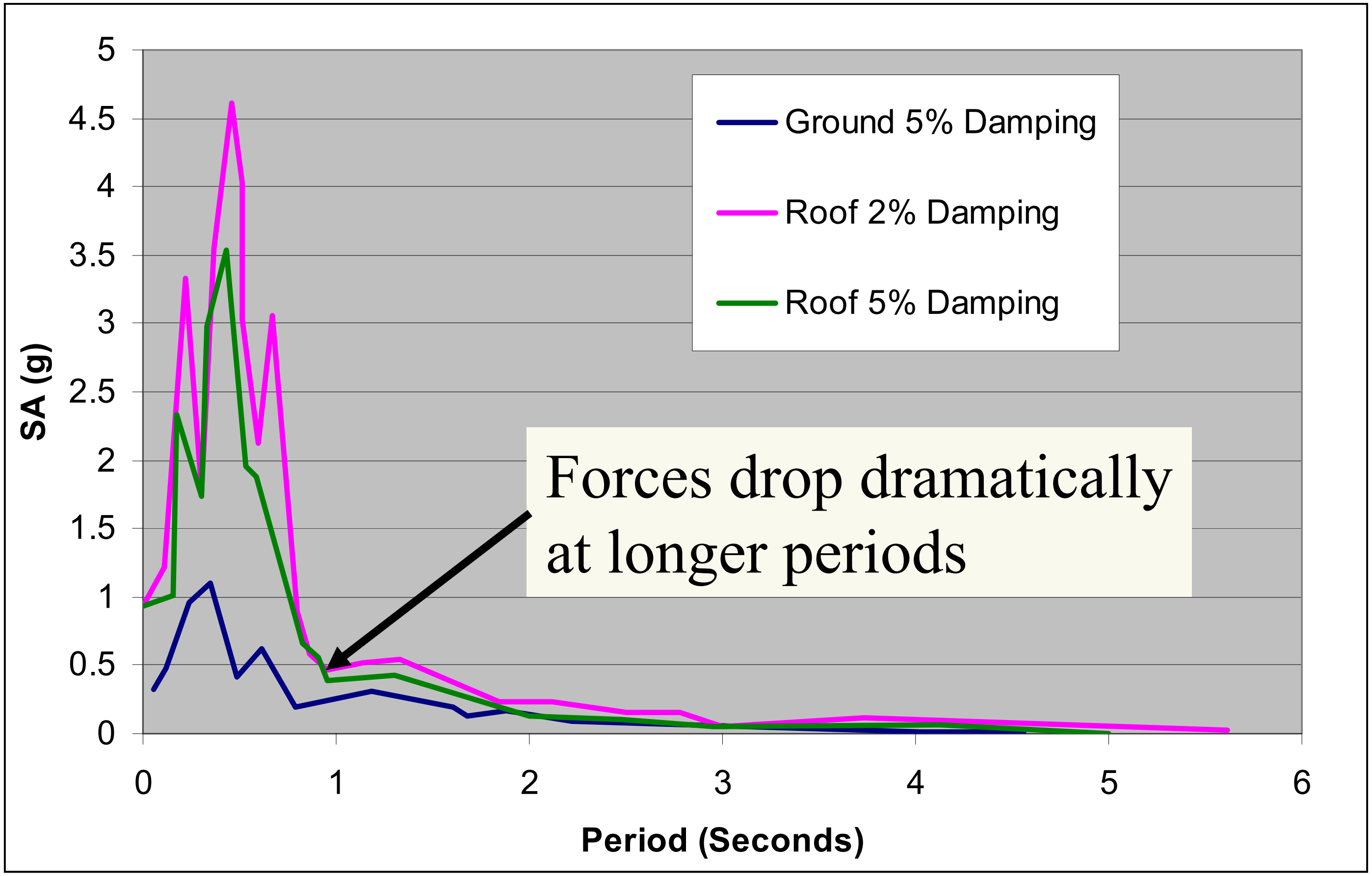
Instrument Records

- Insight into the in-structure acceleration and displacement demands on nonstructural components can gained by examining strong-motion records
- The following data is extracted from *Response of Instrumented Buildings to 1994 Northridge Earthquake, An Interactive Information System,* by Farzad Naeim, John A. Martin & Associates, Inc.

Instrument Records

- Very brief example of the information that can found on 4 buildings:
  - Los Angeles 3-Story Commercial Building
  - Los Angeles 9-Story Office Building
  - Los Angeles 19-Story Office Building
  - Los Angeles 52-Story Office Building
- Floor Response and Displacement Spectra

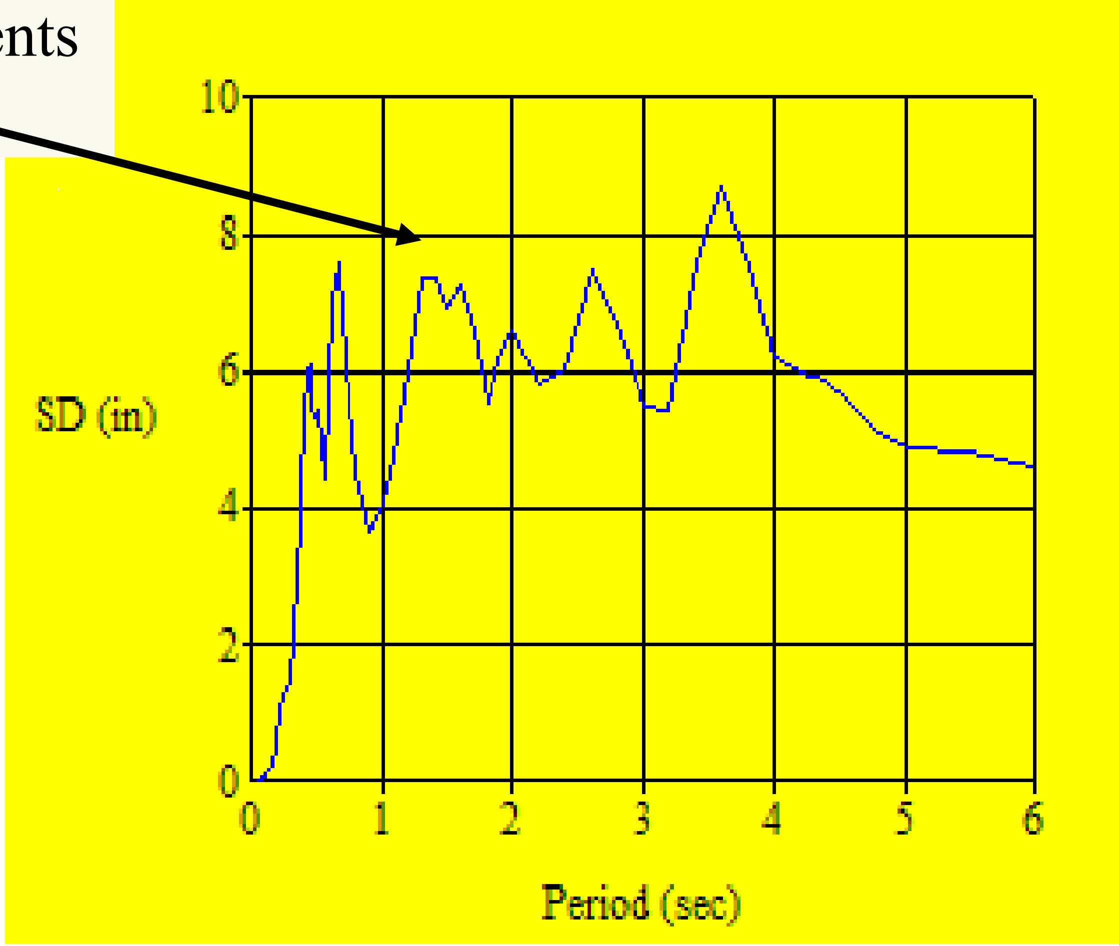
LA 3-Story Building



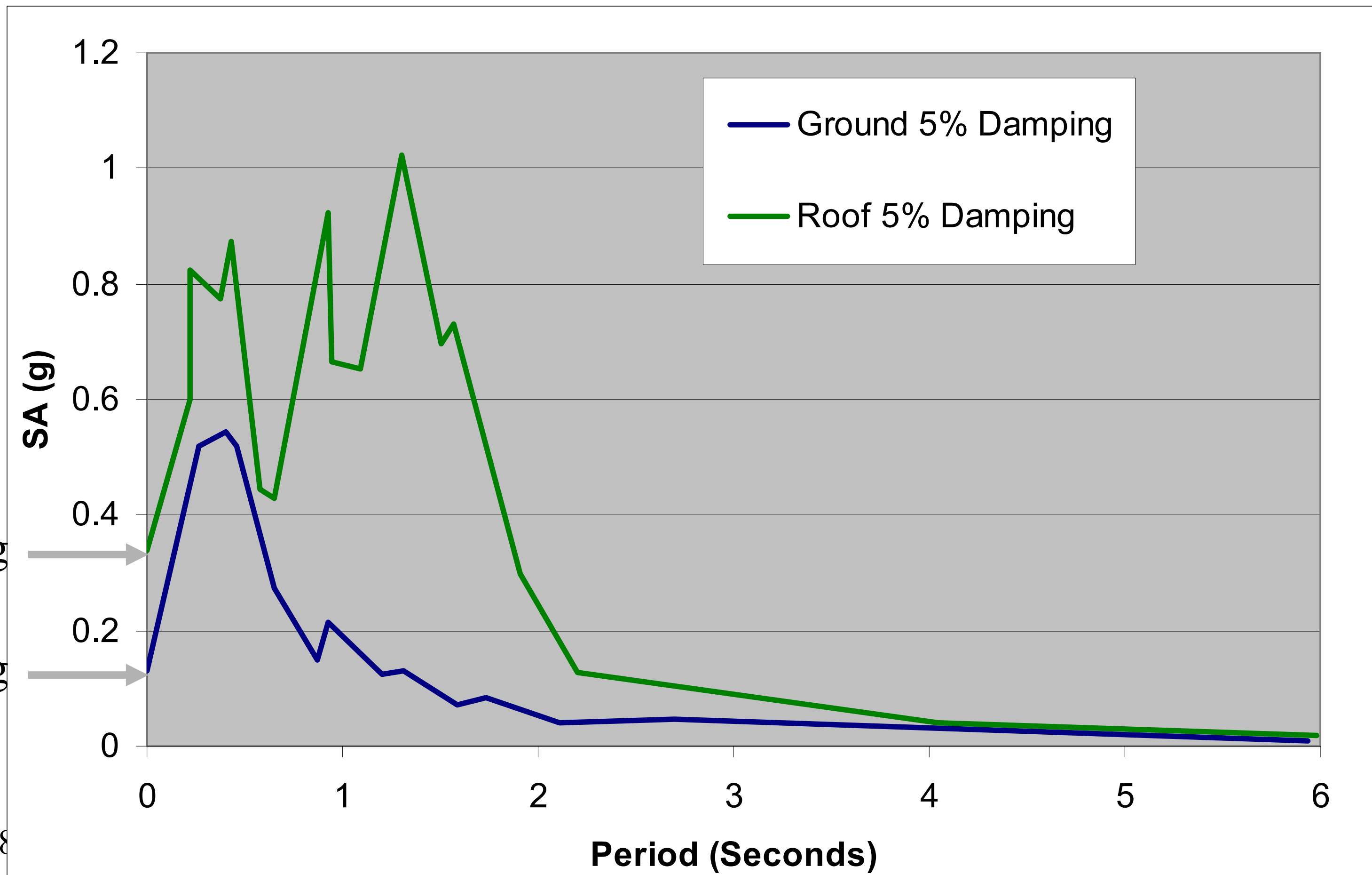
LA 3-Story Building
Roof Displacement Spectra

But displacements increase

5% Damping

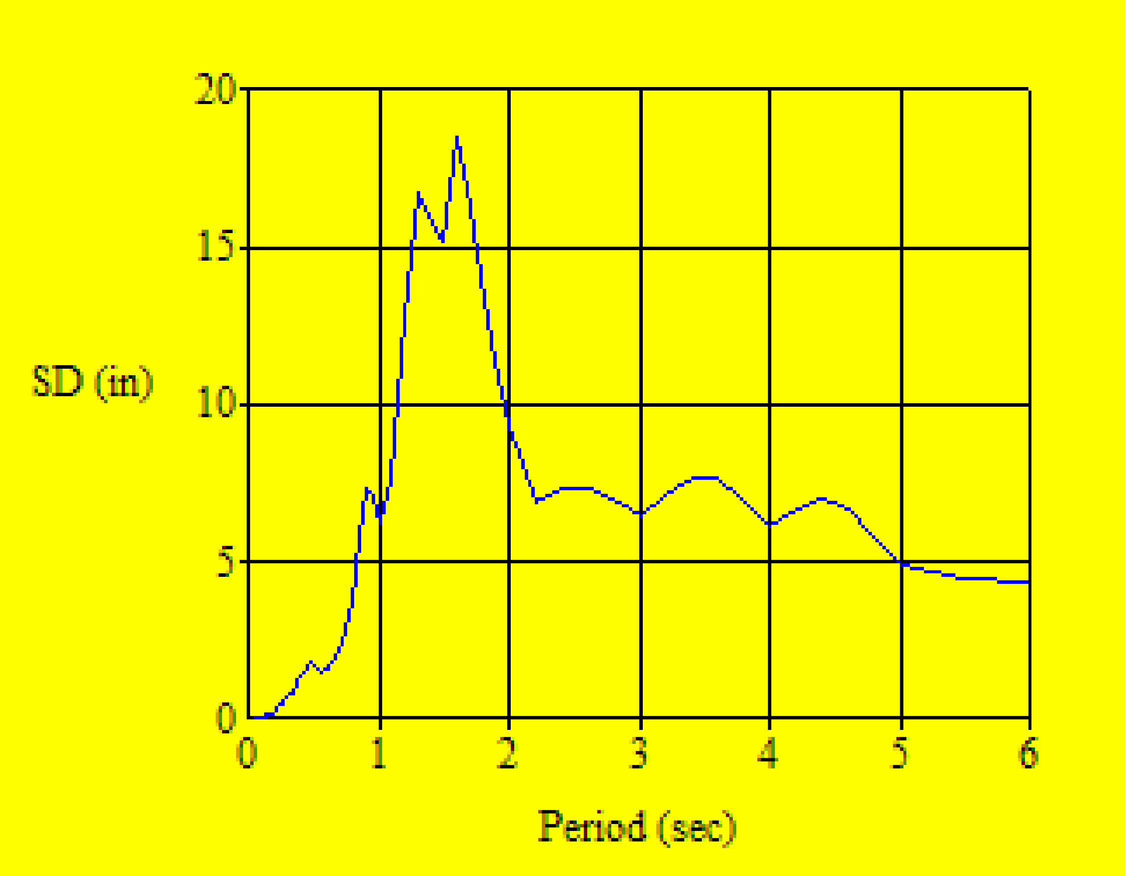


LA 9-Story Building
5% Damping

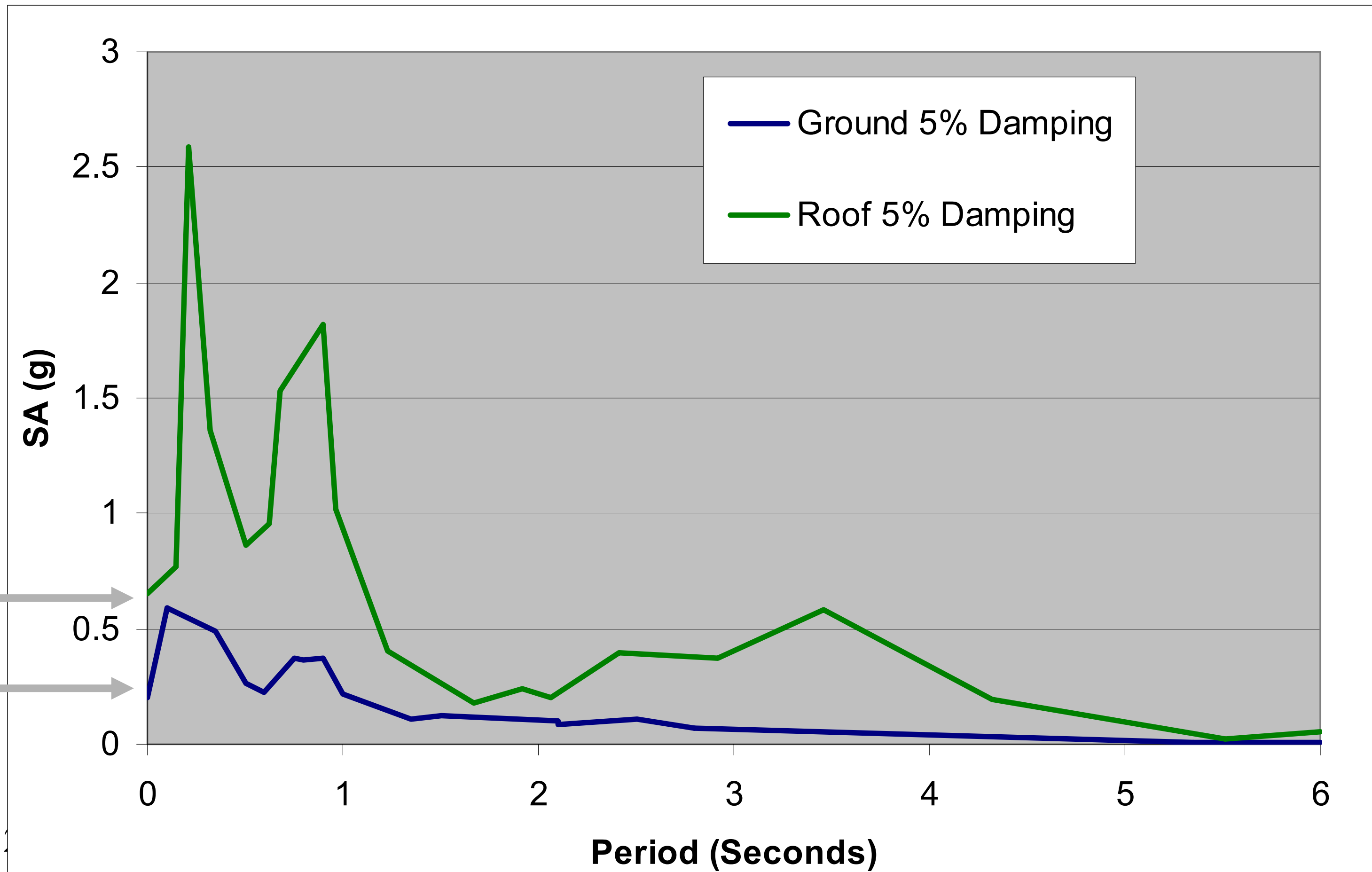


LA 9-Story Building
Roof Displacement Spectra

5% Damping



LA 19-Story Building
5% Damping

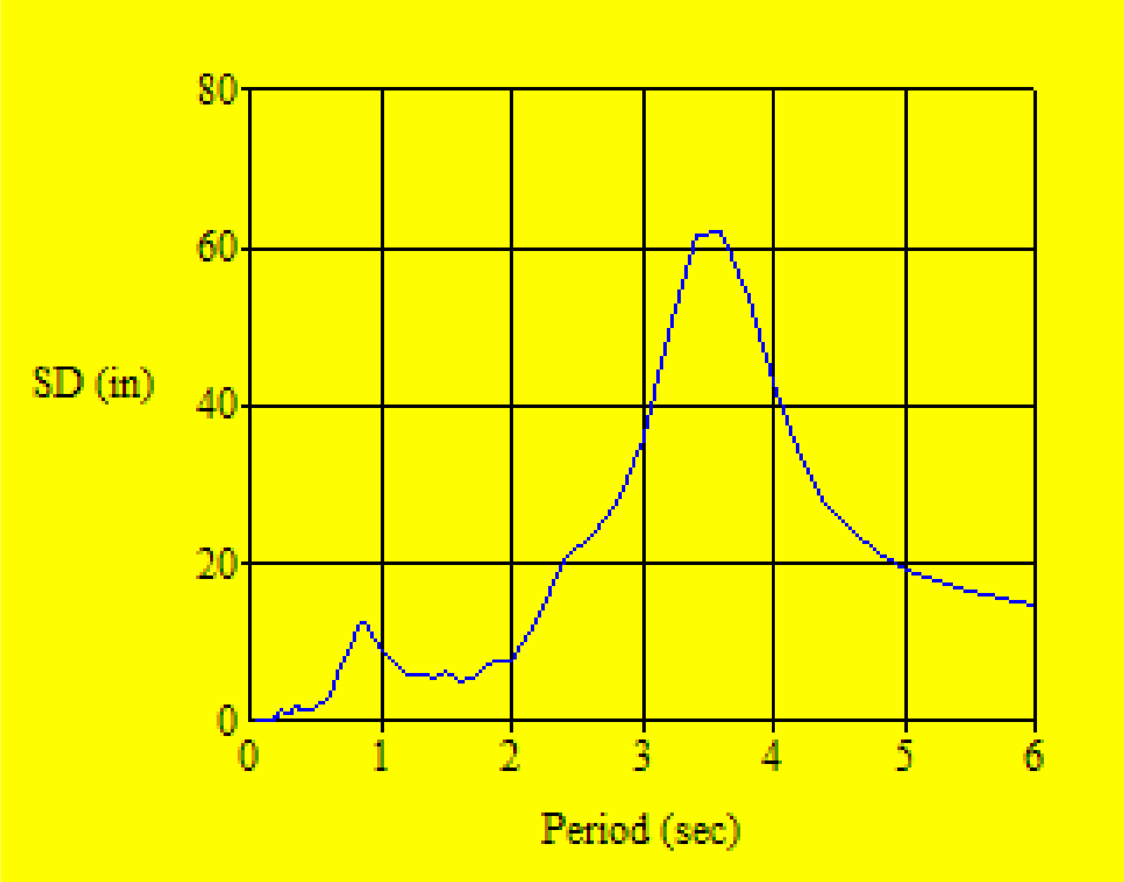


0.65 g

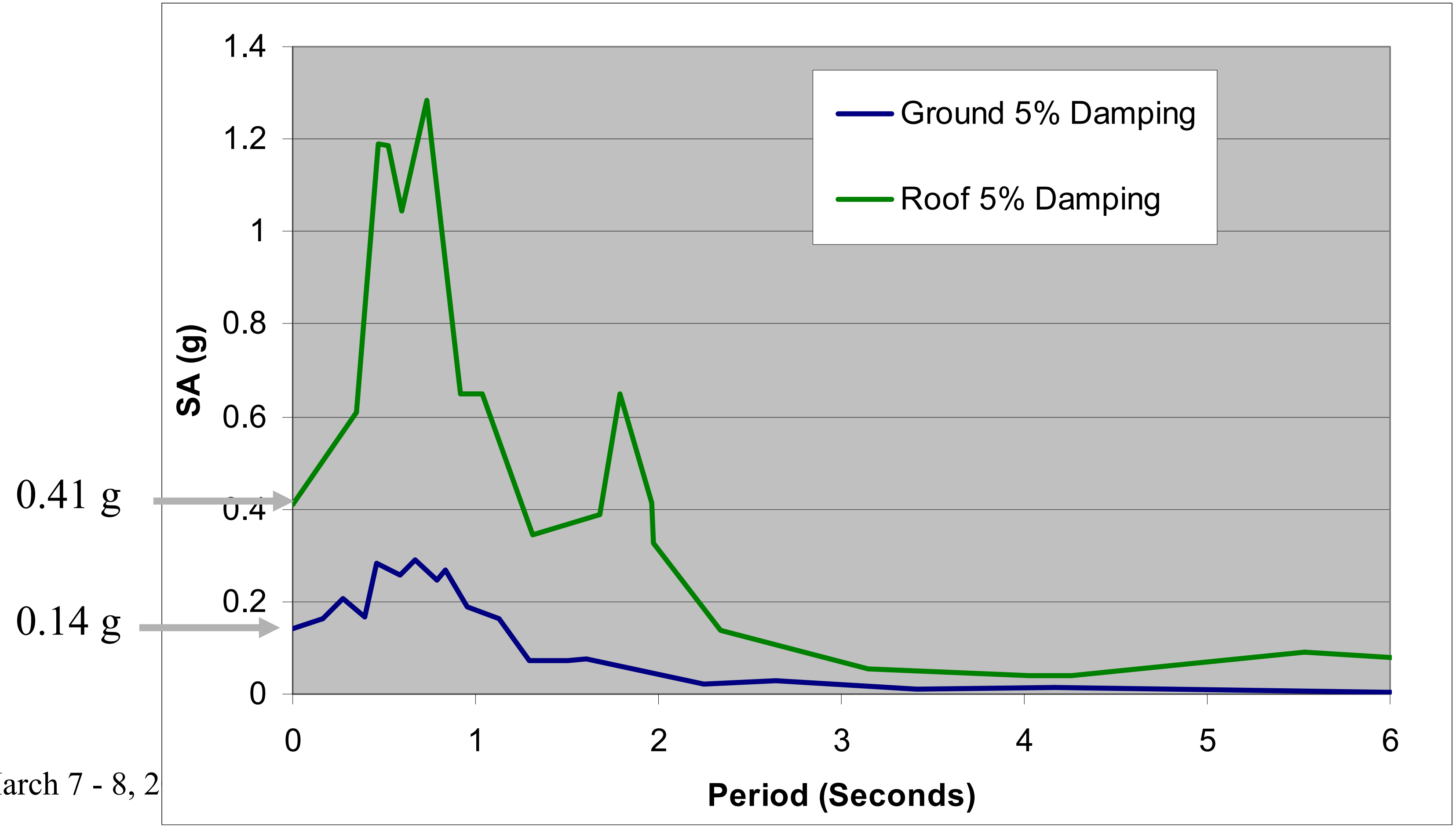
0.20 g

LA 19-Story Building
Roof Displacement Spectra

5% Damping

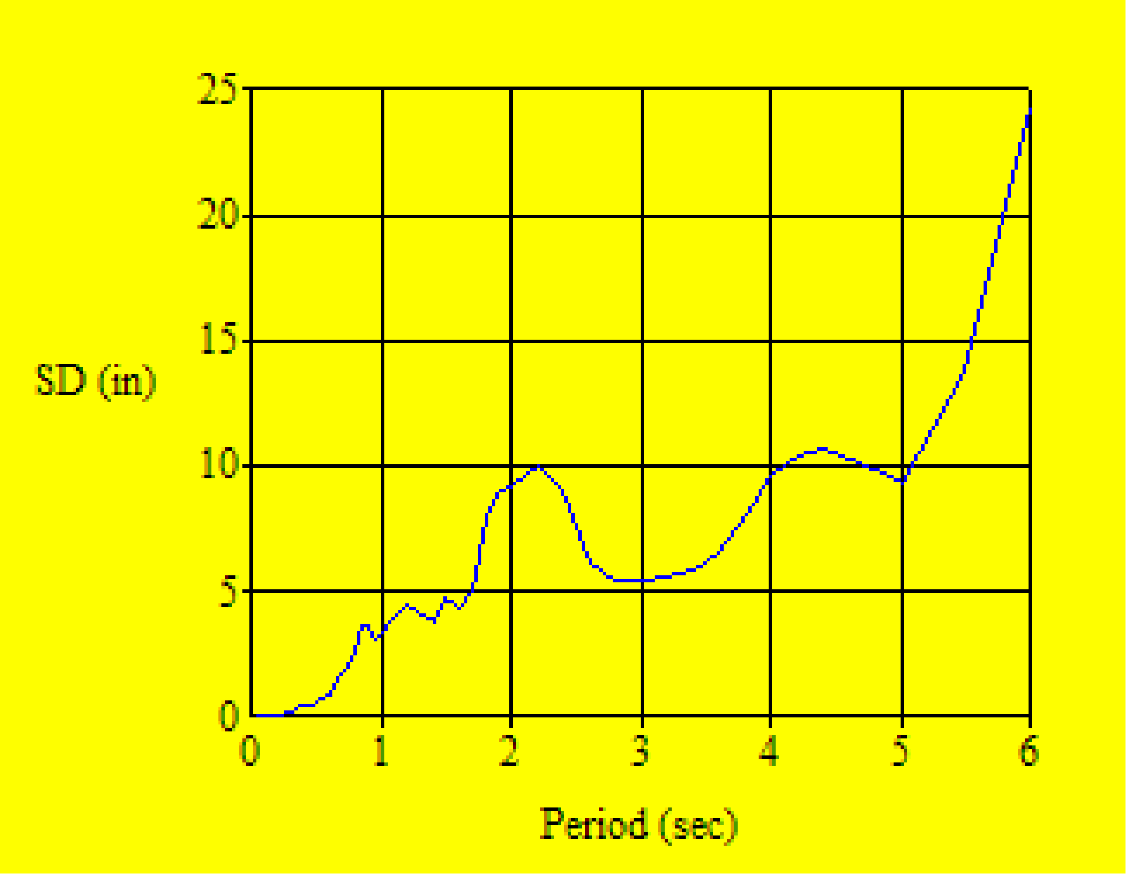


LA 52-Story Building
5% Damping



LA 52-Story Building
Roof Displacement Spectra

5% Damping



Is there consensus on the *Input* EDPs ?

- *Input* EDPs – Relative Anchor Displacements and In-structure accelerations (floor spectra).
- Research needs

  * Criteria for determining when the non-structural component response can be considered decoupled from the structure response.

  * Special characteristics of in-structure acceleration motions. Do they contain velocity pulses?

  * Development of building independent EDPs

Should PEER study NSC *Response* EDPs?

- *Response* EDPs seem very component or system specific
- Can be very complex issue since may be dependent on individual layout of a system (e.g. a piping system).
- Recommend we currently focus on the *Input* EDPs and only study *Response* EDPs if we are doing testing or research on an individual item or system.
- For example, if we are investigating the behavior of storage racks, a *Response* EDP might be the rotational demand on a moment connection or the force in the anchor bolts. Develop a relationship between *Input* and *Response*.

Identifying the Most Significant NSCs

- Which NSCs contribute the most to losses where losses include include direct dollar losses, downtime and injuries/casualties?
- Unaware of any definitive research – needs to be done. Currently an early ATC-58 Task. Where possible need also to relate the losses to *Input* EDPs and what the NSCs fragility was where the loss occurred.
- We also do not know the impact of current code requirements (1997 UBC, 2000 IBC, ASCE 7-02) on the fragility of NSCs.

What Components of Significance Do We Know Least About?

- Piping and plumbing systems
- Ceiling systems
- Certain types of cladding systems
- Ceiling system interactions
- HVAC systems
- Elevators and escalators
- Content storage and protection
- Office equipment fragility (filing cabinets, computers, etc)

Design Strategies for Higher Performance Where Focus is on the Structure

- Design a very stiff building – minimize drift
  Accelerations are generally higher
- Design a flexible ductile building – accelerations lower
  Drifts are generally higher
- Design a base isolated building –
  both drift and accelerations much lower –
  but isolation displacements higher
  Cost appears higher – but is actually lower if operability is your performance goal at design ground motion levels
- Design a building with energy dissipation – in between
  less acceleration and drift – *moderately higher cost*

More Cost Effective to Enhance Performance of Nonstructural Components Themselves?

- Engineers routinely design/specify nonstructural components for higher seismic performance
- Examples
    * Cladding designed for drift
    * Anchorage/bracing design of individual components
    * OSHPD detailing
    * Shake Table Testing (AC-156)

* Very difficult to implement. Tremendous cultural problem in building contracting industry. No responsibility. D/S/I.

Recommendations for PEER Focus

- Develop on fragility data for at lest a few specific components. Should be reliability based fragility data
- For the specific components selected develop *Response* EDPs
- Develop relationship between *Input* and *Response* EDPs
- Evaluate significance and impact on losses dependent on the *Response* EDPs for the specific components
- Correlate the losses to the Decision Variables
- Basically complete the PEER vision from start to finish on at least a few significant components and systems.

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Performance Based Earthquake Engineering for Nonstructural Components

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2003 PEER Annual Meeting, Palm Springs March 7, 2003

Introduction

PBEE is full of interesting challenges

Some of the most difficult and important challenges are in the area of NONSTRUCTURAL COMPONENTS

Introduction

- 1989 Loma Prieta earthquake
- 1994 Northridge earthquake
- 1995 Hyogo-ken-Nambu earthquake

SEAOC Vision 2000

ATC-33, FEMA 273, FEMA 356

ATC 40

ATC 55

ATC 158

AND PERHAPS ALSO PEER !

Need for predictable performance

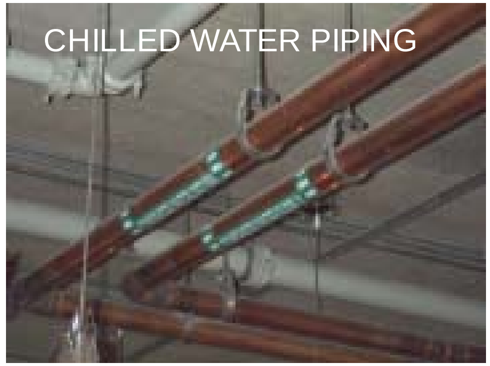
Need for loss control

Objectives

Discuss research needs in the area of nonstructural components (in particular areas in which PEER can contribute)

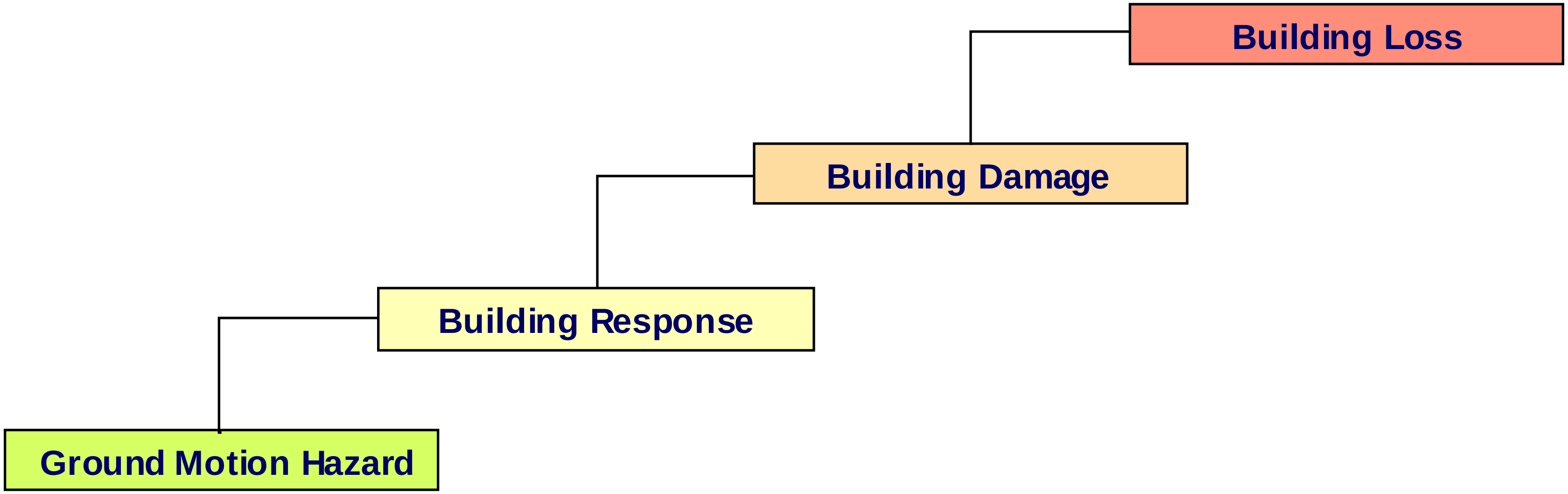
My role here is just to present a brief summary of challenges in the area on nonstructural components

PBEE Challenges for Nonstructural Components



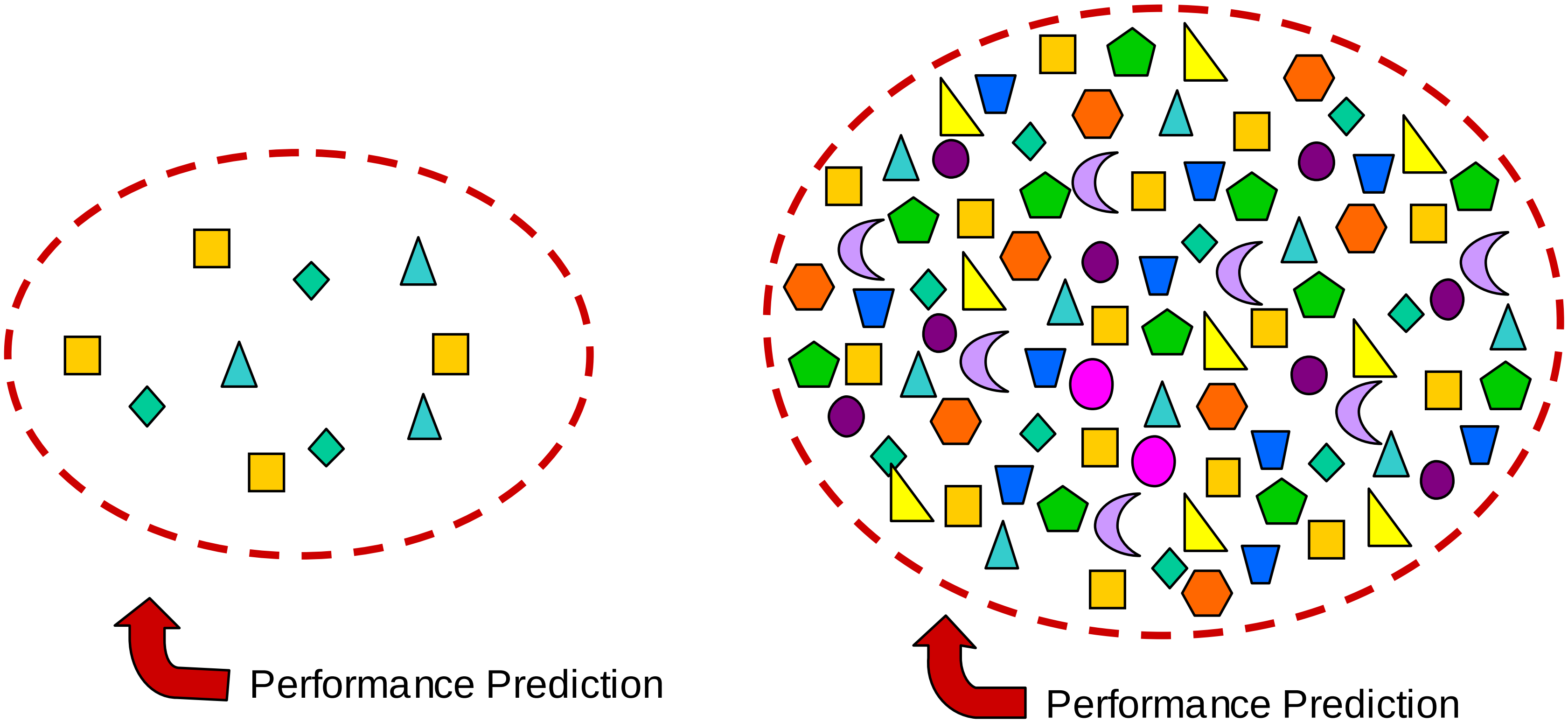
Challenges

Where are the challenges ?



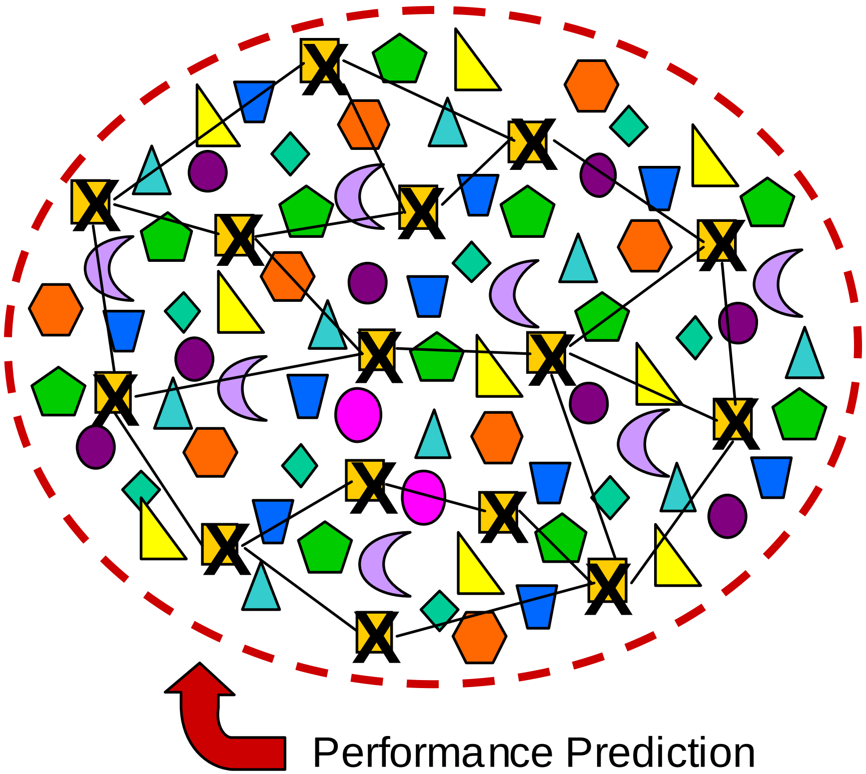
Challenge No. 1

There are many nonstructural components and many types of nonstructural components



Challenge No. 2

Many nonstructural components are part of an operating system



Performance Prediction

Challenge No. 3

IM's that reduce dispersion in structural EDP's may not reduce the dispersion of nonstructural EDP's

PGA vs. $S_a(T_1)$

Challenge No. 4

Much more EDP's to consider

It is not very clear which ones are more appropriate

Challenges in selection of EDP's

PEAK MOTION PARAMETERS

IDR

PFA

PFV (absolute)

PIFV (absolute)

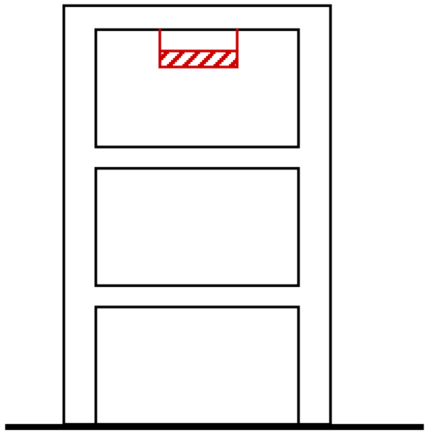
If component is on ground level

PGA

PGV

PIV

Challenges in selection of EDP's



PEAK MOTION OF SDOF OSCILLATOR

$S_{FA}(T_c, \xi_c)$

$S_{FV}(T_c, \xi_c)$

$S_{FD}(T_c, \xi_c)$

If component is on ground level

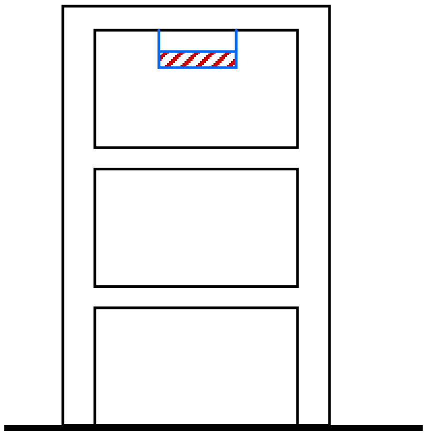
$S_A(T_c, \xi_c)$

$S_V(T_c, \xi_c)$

$S_D(T_c, \xi_c)$

Challenges in selection of EDP's

PEAK MOTION OF *NONLINEAR* SDOF OSCILLATOR



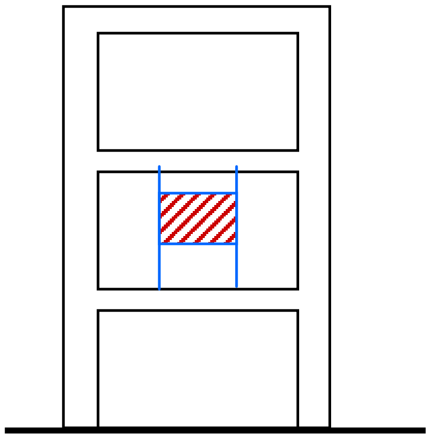
$\Delta_i(T_c, \xi_c, F_{yc})$

$\Delta_r(T_c, \xi_c, F_{yc})$

$\mu(T_c, \xi_c, F_{yc})$

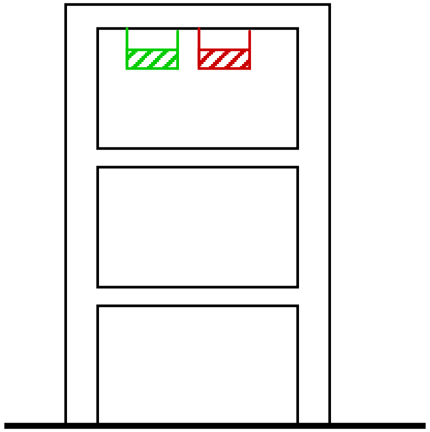
Challenges in selection of EDP's

PEAK RELATIVE MOTION OF A LINEAR OR NONLINEAR SDOF OSCILLATOR *BUT WITH MULTIPLE SUPPORT EXCITATION*



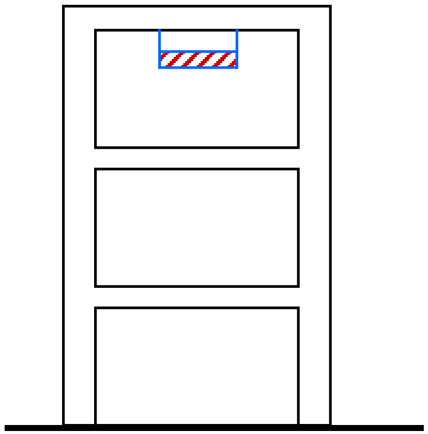
Challenges in selection of EDP's

PEAK RELATIVE MOTION OF TWO SDOF OSCILLATORS



Challenges in selection of EDP's

MEASURES OF *CUMULATIVE DAMAGE* IN NONLINEAR SDOF OSCILLATORS



NYR (T_c, ξ_c, F_{yc})

$E_H(T_c, \xi_c, F_{yc})$

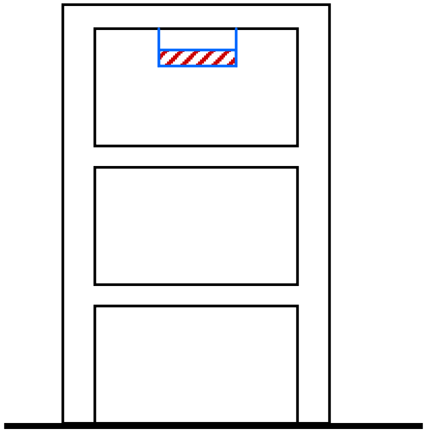
Duration (T_c, ξ_c, F_{yc})

Equiv. N_{cycles} (T_c, ξ_c, F_{yc})

Etc.

Challenges in selection of EDP's

RESPONSE PARAMETERS OF THE ACTUAL NONSTRUCTURAL COMPONENT



Rotation Demand

Strain Demand

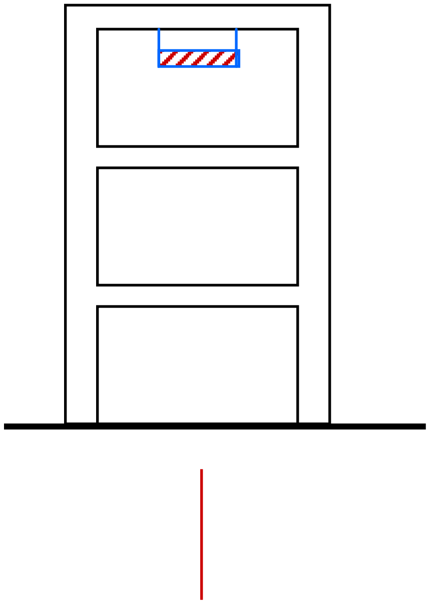
Shear Force Demand

Moment Demand

Etc.

Challenges in selection of EDP's

ALL OF THE ABOVE BUT WITH *VERTICAL MOTION*



Challenge No. 5

Prediction of EDP's can be quite difficult

Challenge No. 6

Prediction of EDP's for nonstructural components probably involves at least three levels:

1. Structural Engineering Perspective
2. Subcontractor Perspective
3. Manufacturer Perspective

Subcontractor need of EDP's

SEISMIC RESTRAINT MANUAL

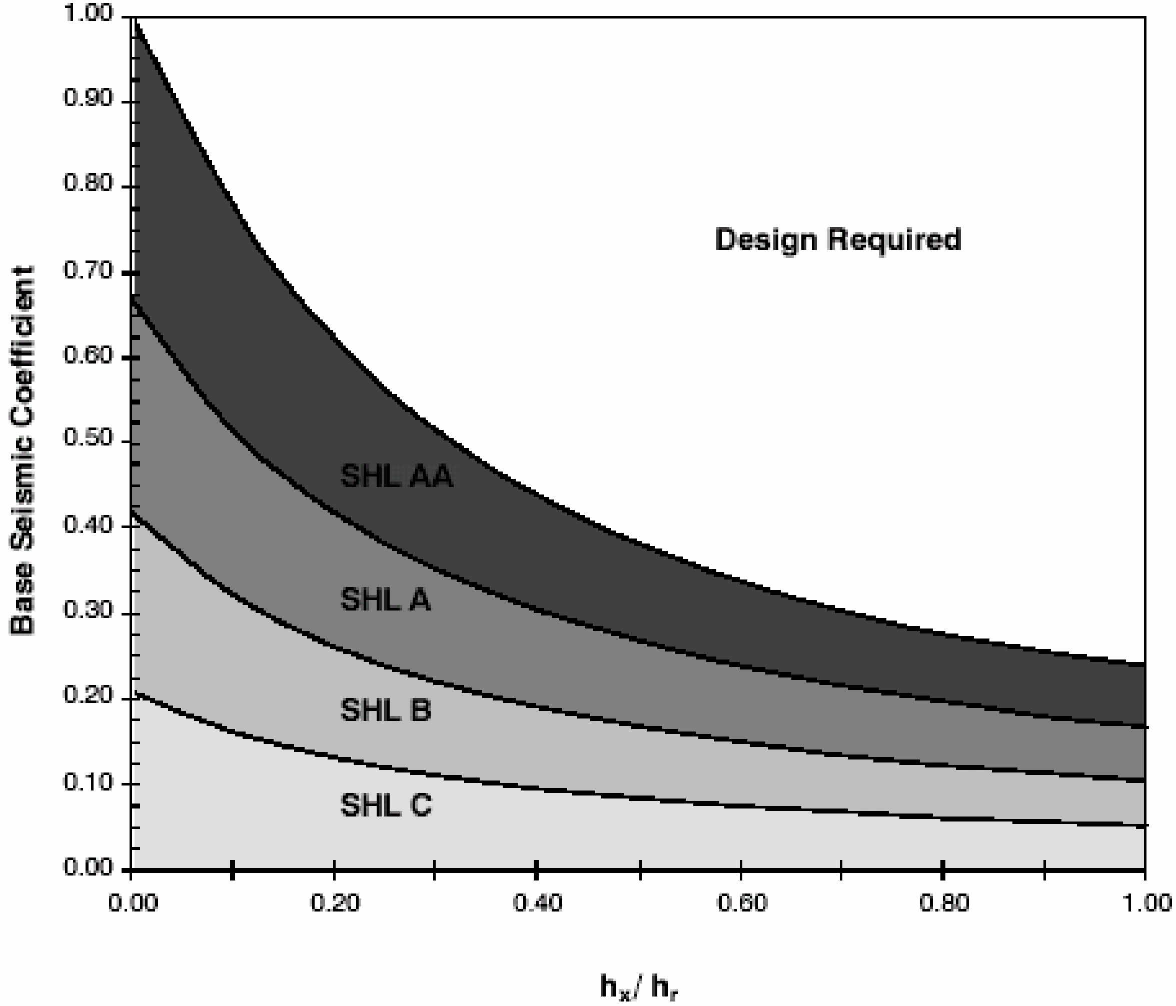
GUIDELINES FOR

MECHANICAL SYSTEMS

SECOND EDITION – 1998

SMACNA

Subcontractor need of EDP's



Subcontractor need of EDP's

Duct Size W × D [1] (in.)	Vertical Legs Angles (in.)	Horizontal Beams Angles (in.)	Diagonal Brace [2] Angles (in.)	Bolt Size (in.)	Connection Type [3]	Max. Wt. Per Ft [4] (lb)
30 × 30	2 × 2 × 3/16	2 × 2 × 3/16	2 × 2 × 16ga	3/8	D	17
42 × 42	2 × 2 × 3/16	2 × 2 × 3/16	2 × 2 × 12ga	½	F	29
54 × 54	2 × 2 × 3/16	2½ × 2½ × ¼	3 × 3 × 12ga	5/8	F	46
60 × 60	2 × 2 × 3/16	2½ × 2½ × ¼	4 × 4 × 12ga	5/8	G	54
84 × 84	2½ × 2½ × ¼	4 × 3 × ¼	2½ × 2½ × ¼	¾	H	103
96 × 96	2½ × 2½ × ¼	4 × 3 × ¼	3 × 3 × ¼	7/8	I	129
54 × 28	2 × 2 × 3/16	2 × 2 × 3/16	2½ × 2½ × 12ga	½	F	34
60 × 30	2 × 2 × 3/16	2½ × 2½ × ¼	2½ × 2½ × 12ga	½	F	39
84 × 42	2 × 2 × 3/16	2½ × 2½ × ¼	2 × 2 × ¼	5/8	H	74
96 × 48	2½ × 2½ × ¼	3 × 3 × ¼	2 × 2 × ¼	¾	H	91
108 × 54	2½ × 2½ × ¼	4 × 3 × ¼	2½ × 2½ × ¼	¾	H	110
120 × 60	2½ × 2½ × ¼	5 × 3 × 3/8	2½ × 2½ × ¼	¾	I	121

Table AA-5 Floor Supported Ducts, SHL AA

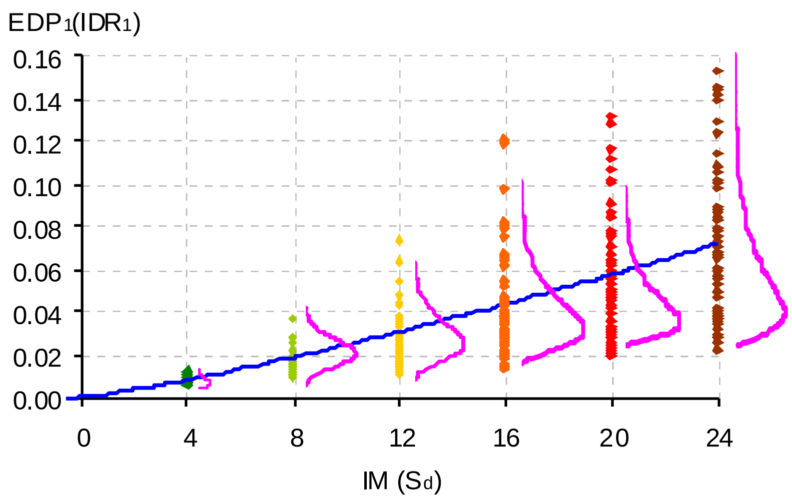
Challenges in Predicting EDP's

is contributing !

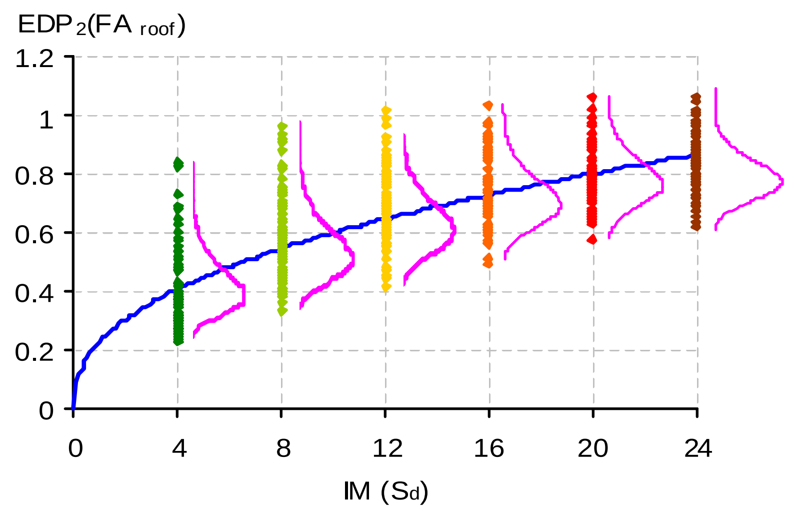
Probabilistic EDP Assessment (*PEER's approach*)

$$P(EDP > edp \mid IM = im)$$

Interstory Drift Ratio

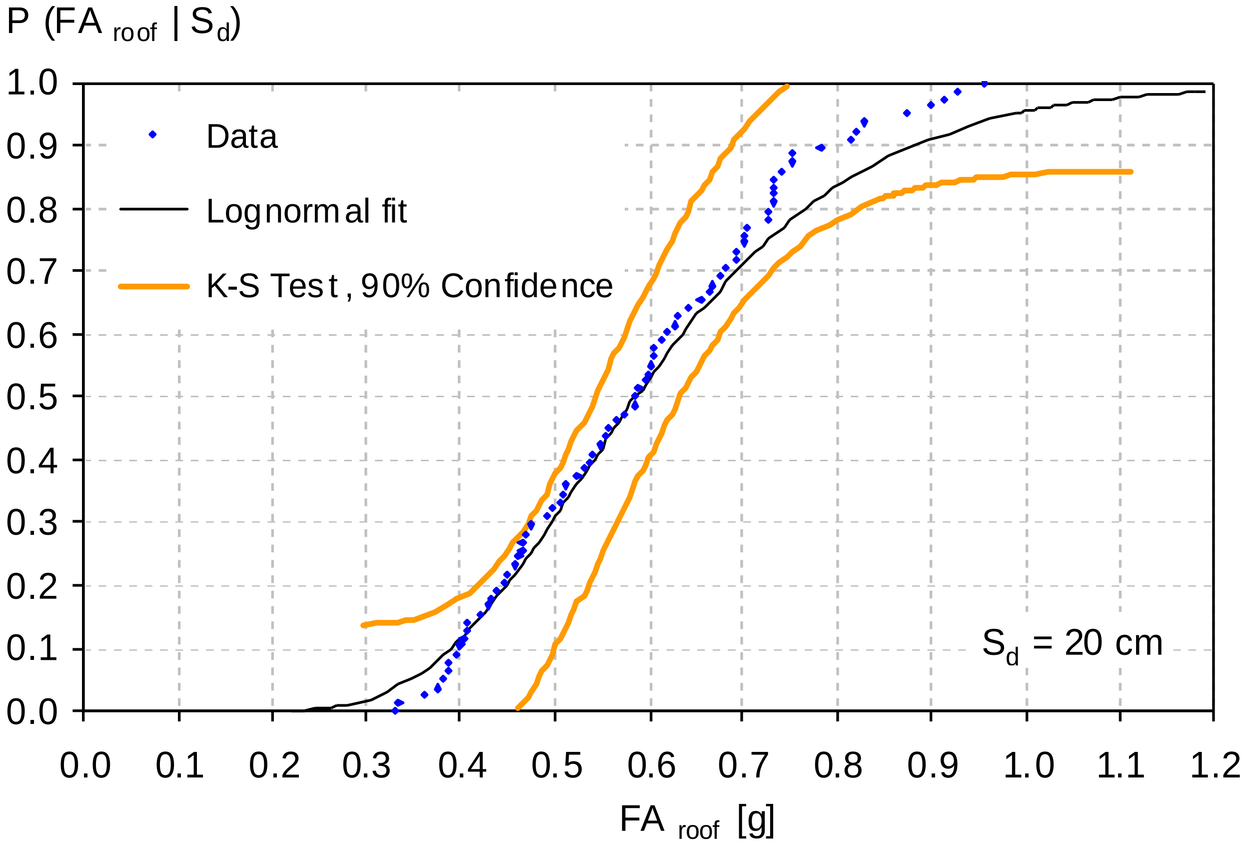


Peak Floor Acceleration

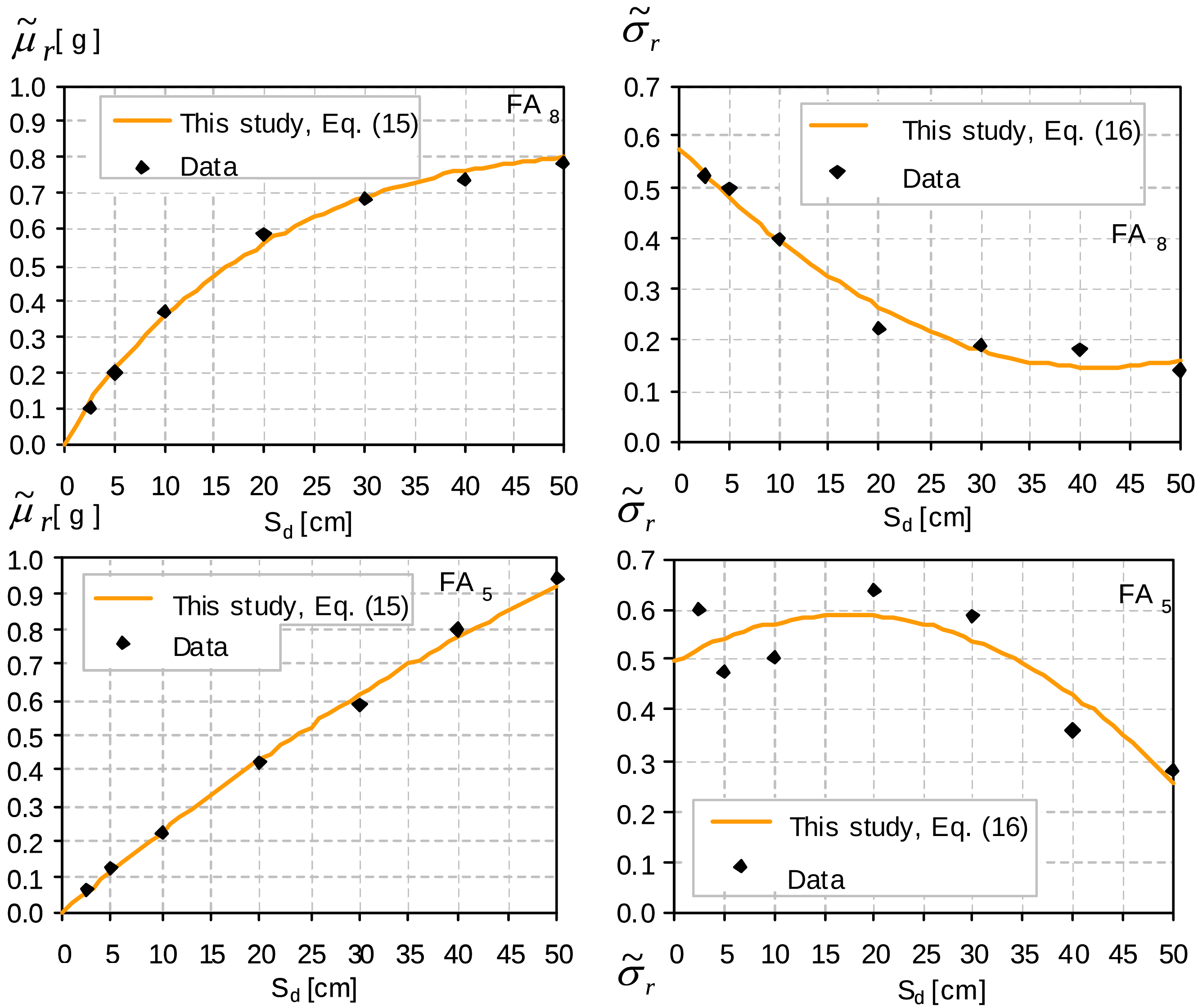


Probabilistic EDP Assessment (*PEER's approach*)

$$P(EDP > edp \mid IM = im)$$

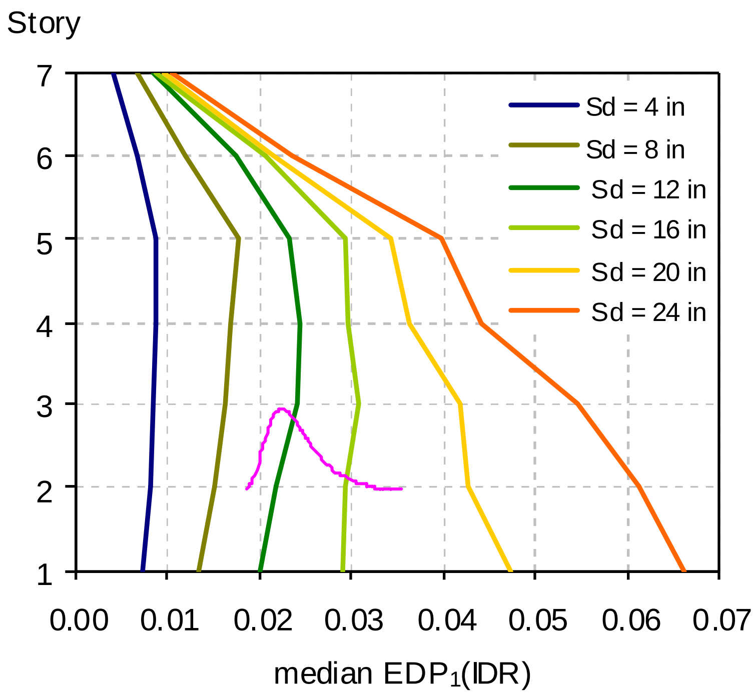


Probabilistic EDP Assessment (*PEER's approach*)

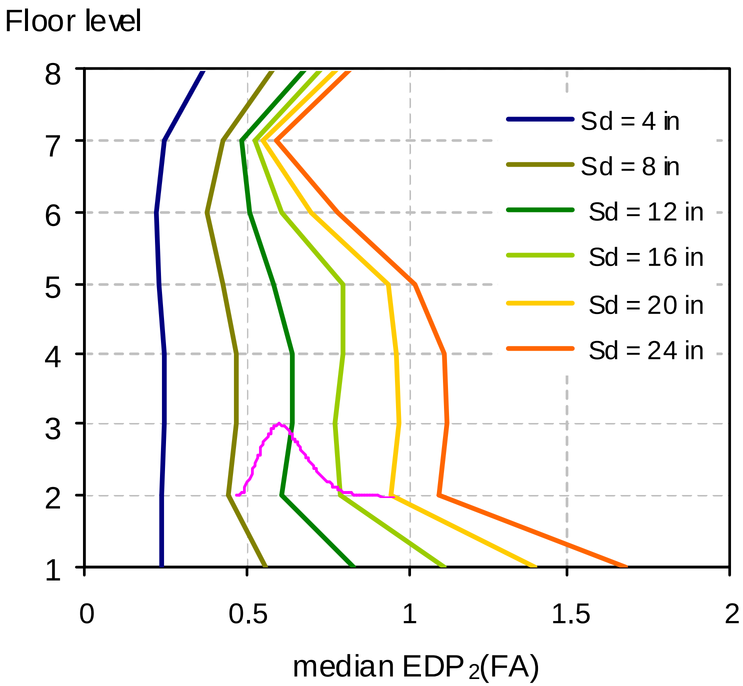


Probabilistic EDP Assessment (*PEER's approach*)

Interstory Drift Ratio



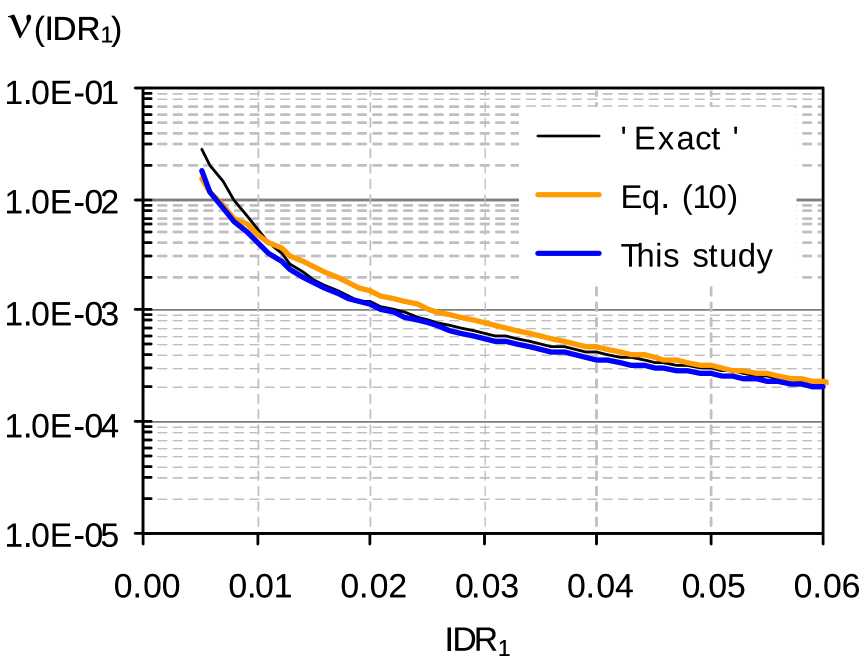
Peak Floor Acceleration



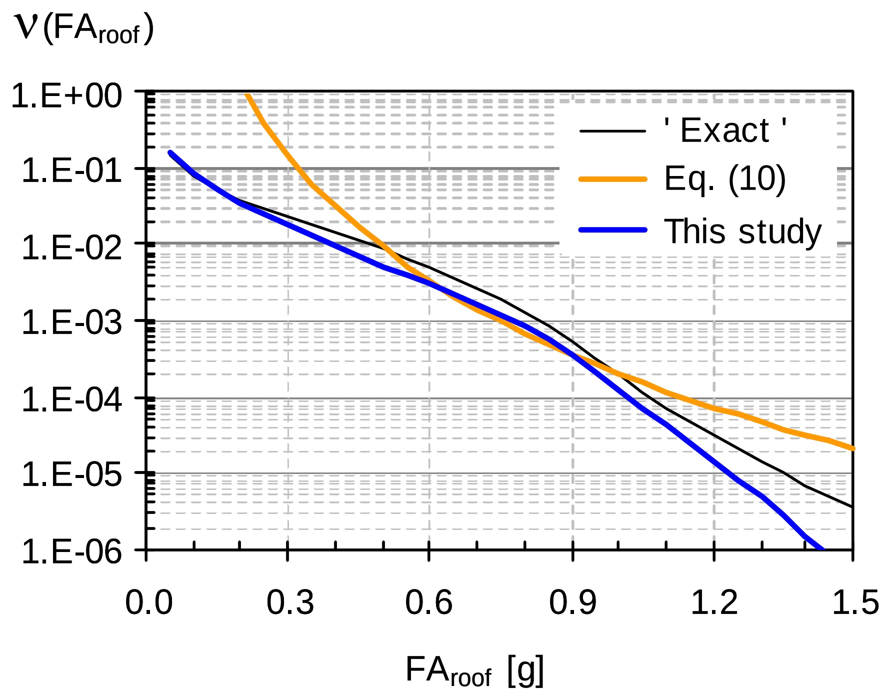
Probabilistic EDP Assessment (*PEER's approach*)

$$P(EDP > edp) = \int_0^\infty P(EDP > edp \mid IM = im) \left| \frac{d\,\nu(IM)}{dIM} \right| dIM$$

Interstory Drift Ratio – First Floor

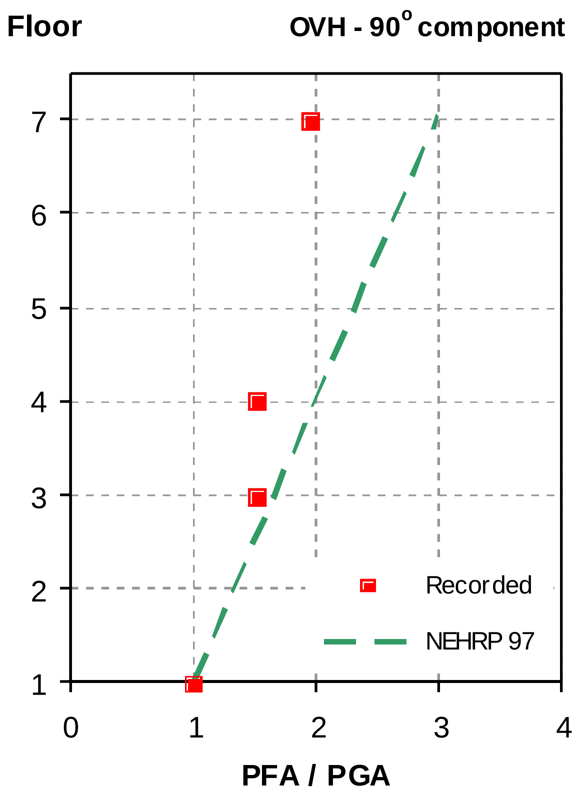


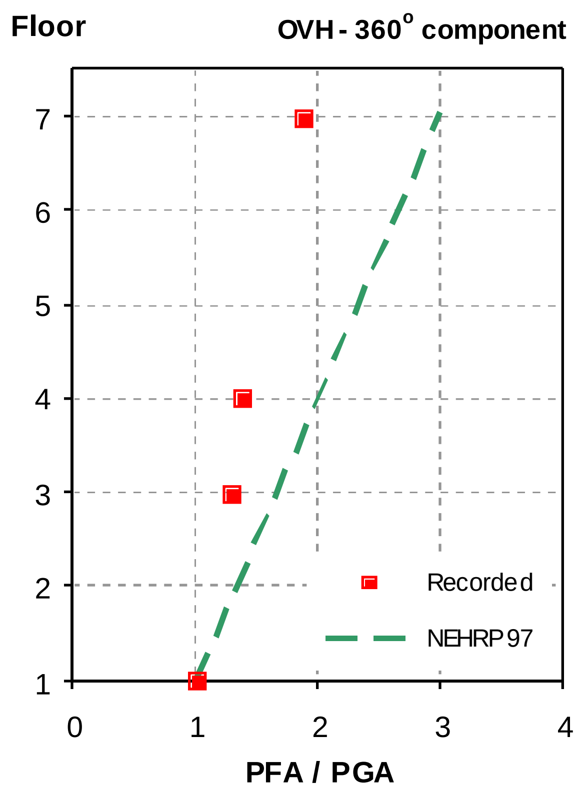
Peak Roof Acceleration



Challenges in Predicting EDP's

Amplification of Peak Floor Acceleration (PFA) along the height of a building





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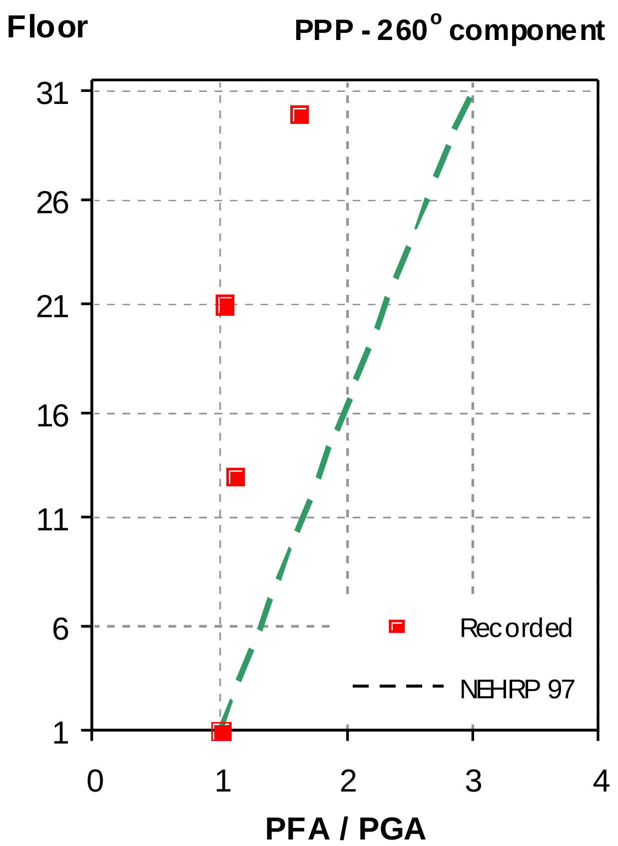

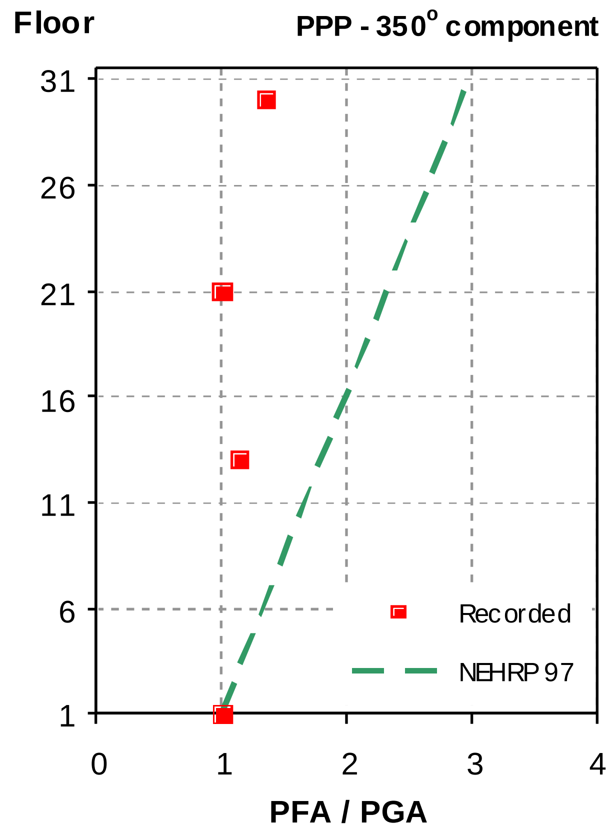

Challenges in Predicting EDP's

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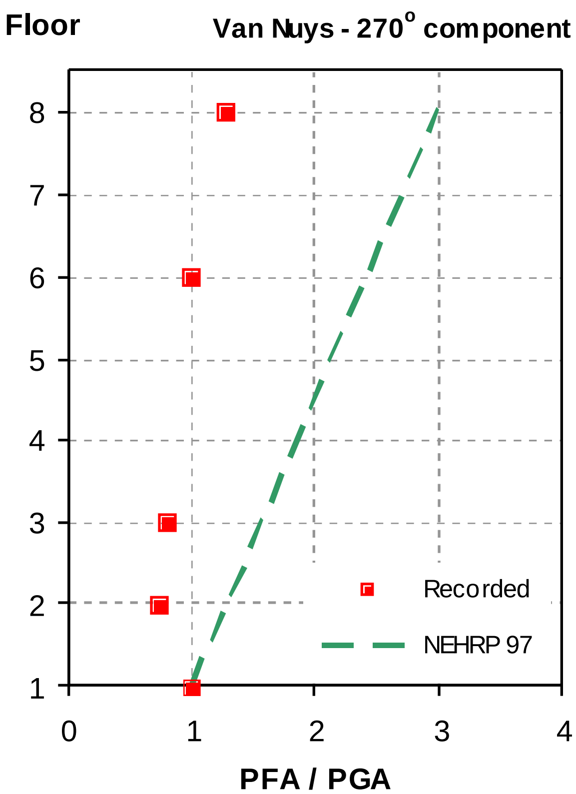
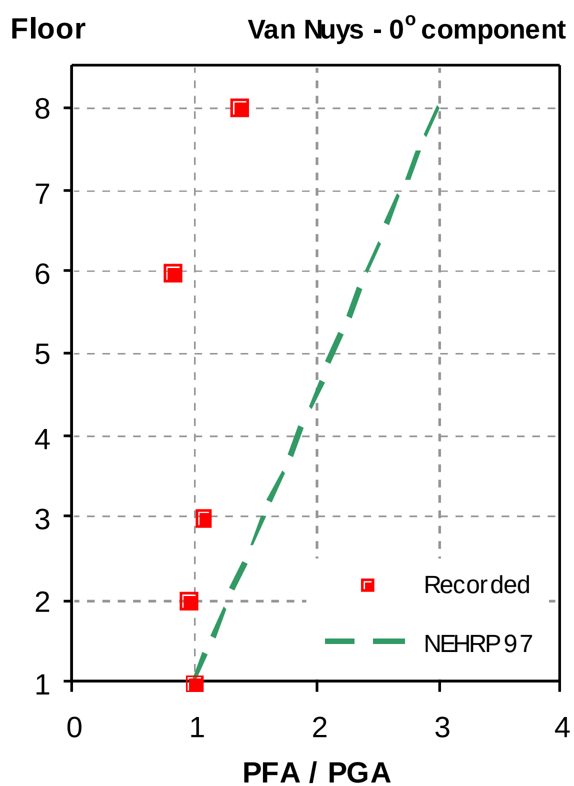
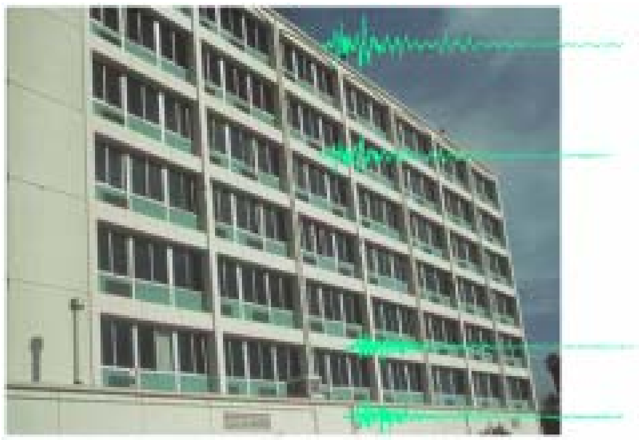
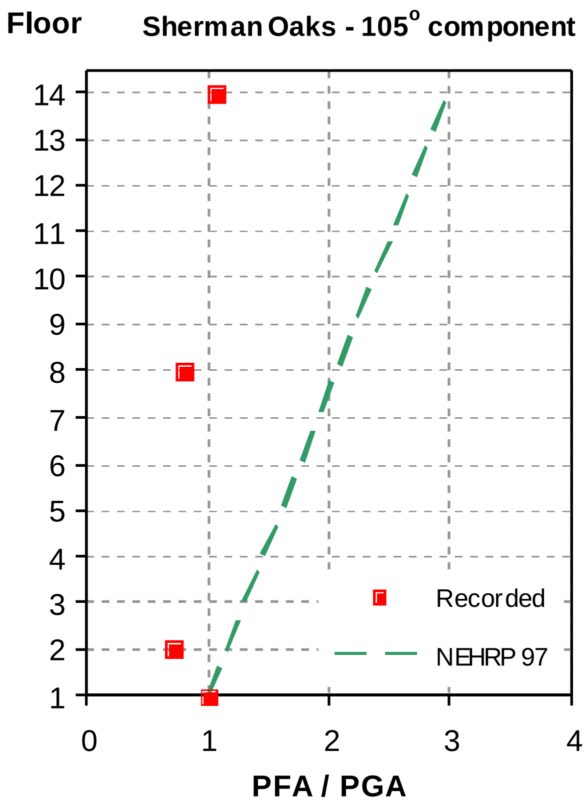


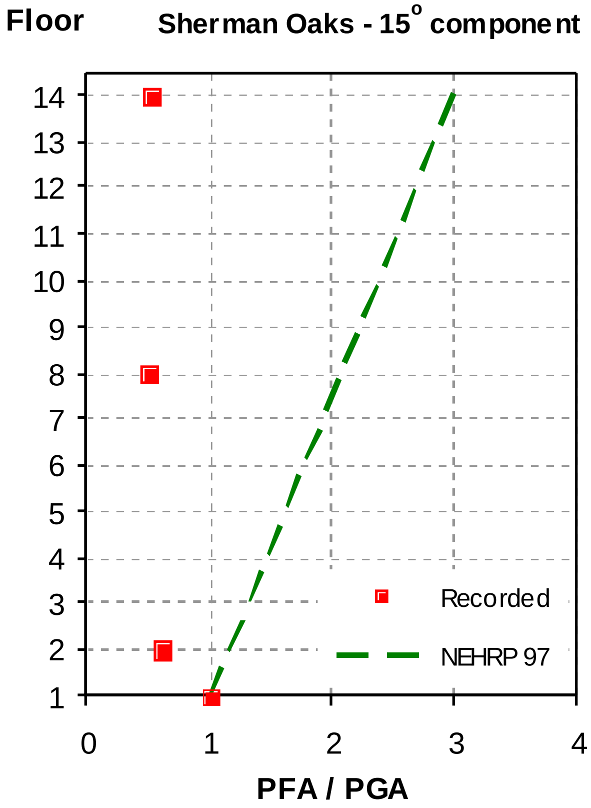




Challenges in Predicting EDP's

Amplification of Peak Floor Acceleration (PFA) along the height of a building

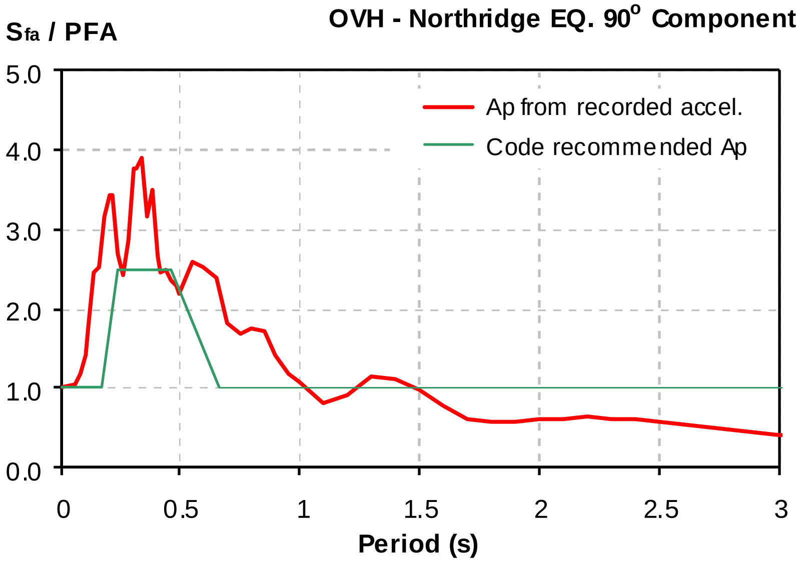


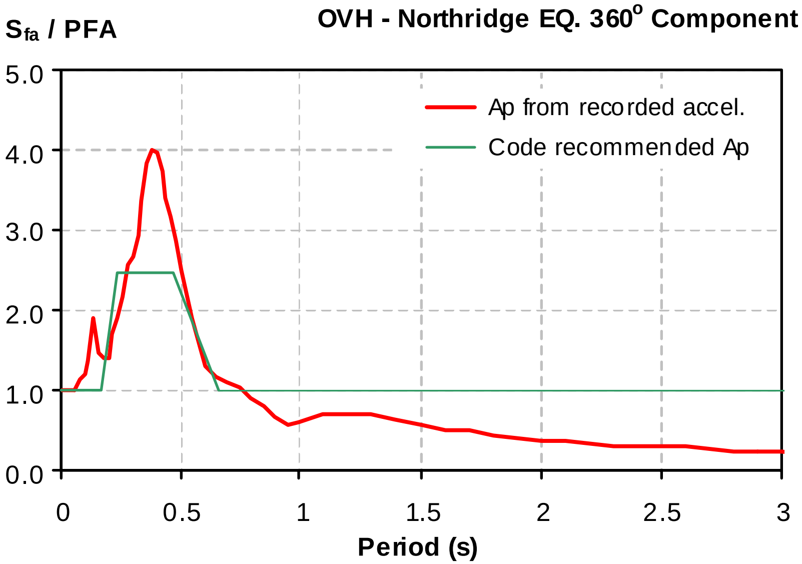


Challenges in Predicting EDP's

Amplification of the peak floor acceleration by a SDOF system

(Component Amplification Factor a_p)





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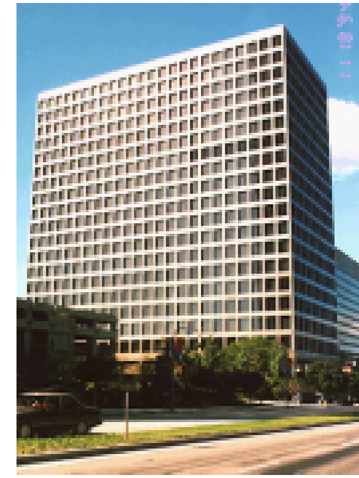

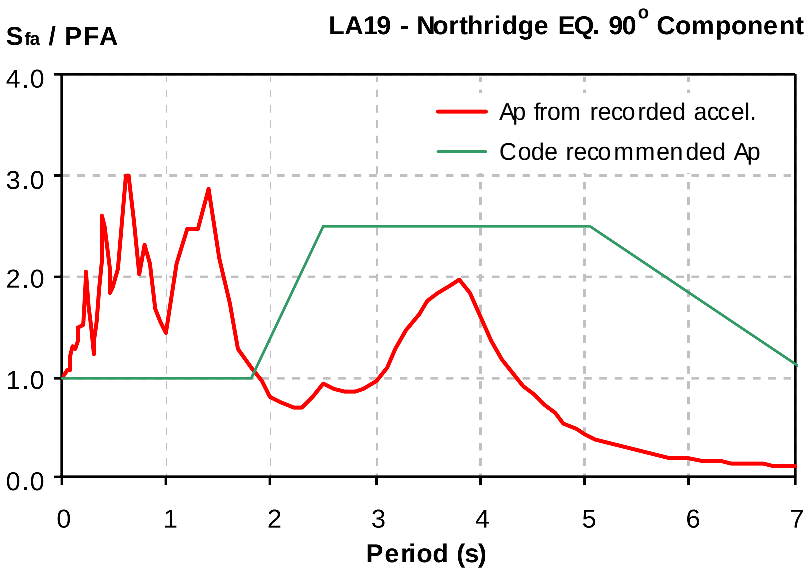

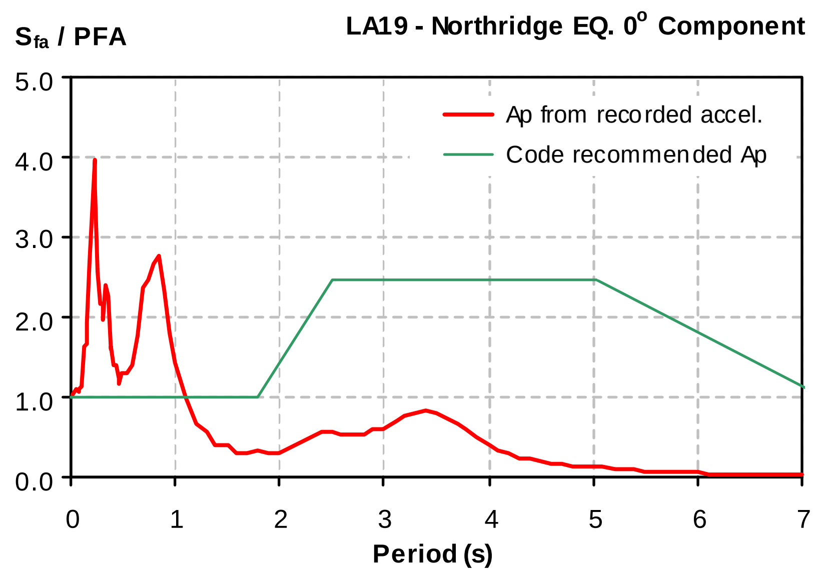

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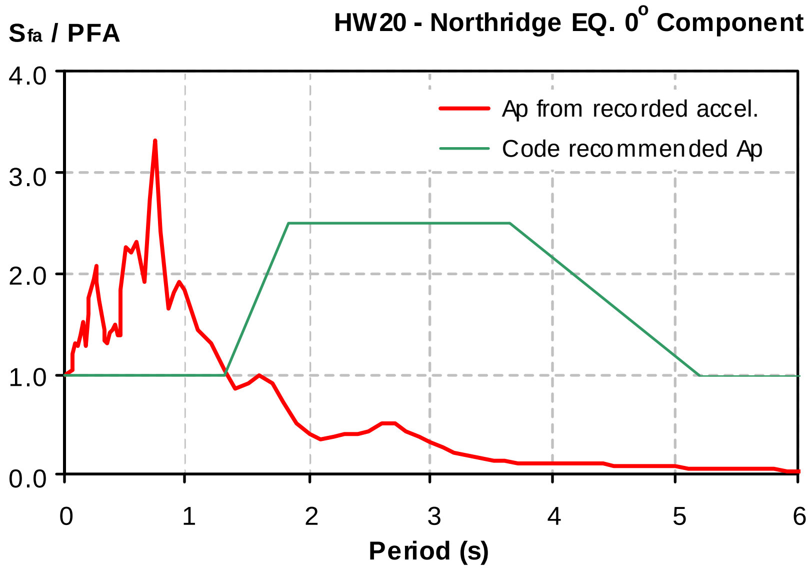

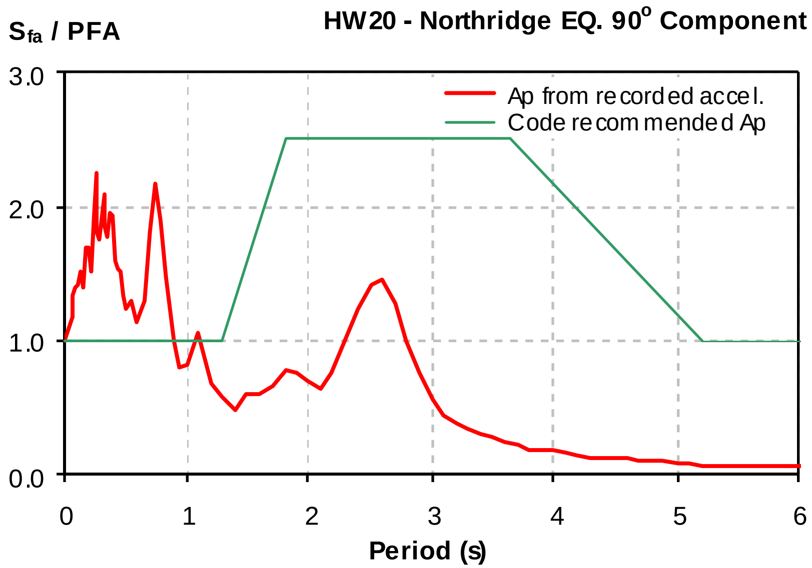

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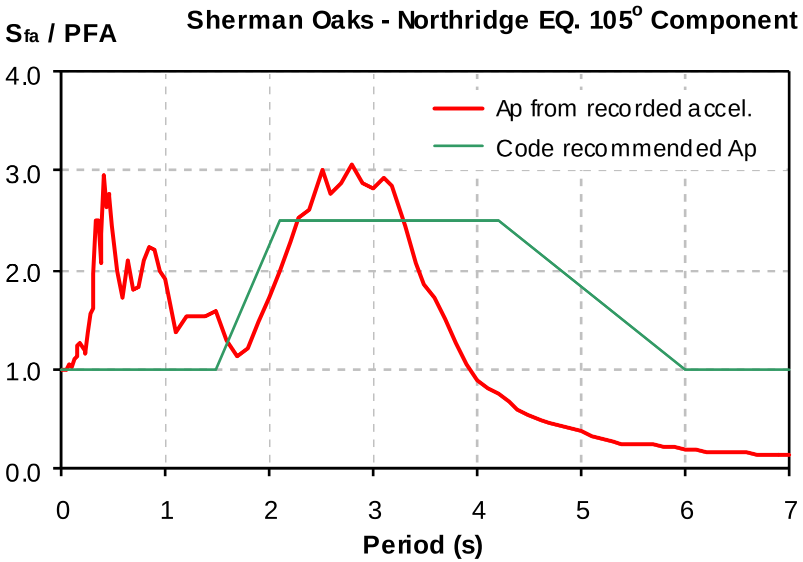

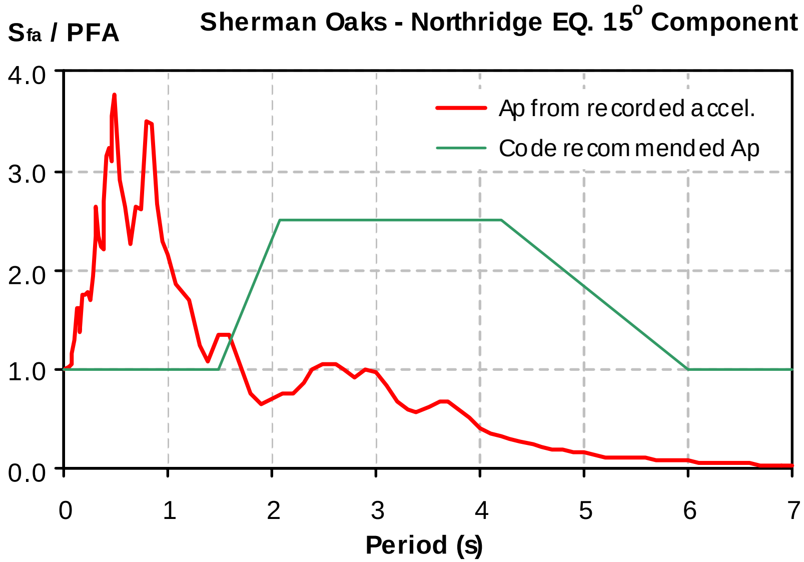

PEER

Challenges in Predicting EDP's

PACIFIC EARTHQUAKE ENGINEERING RESEARCH ***is helping here too !***

Challenges in Predicting EDP's

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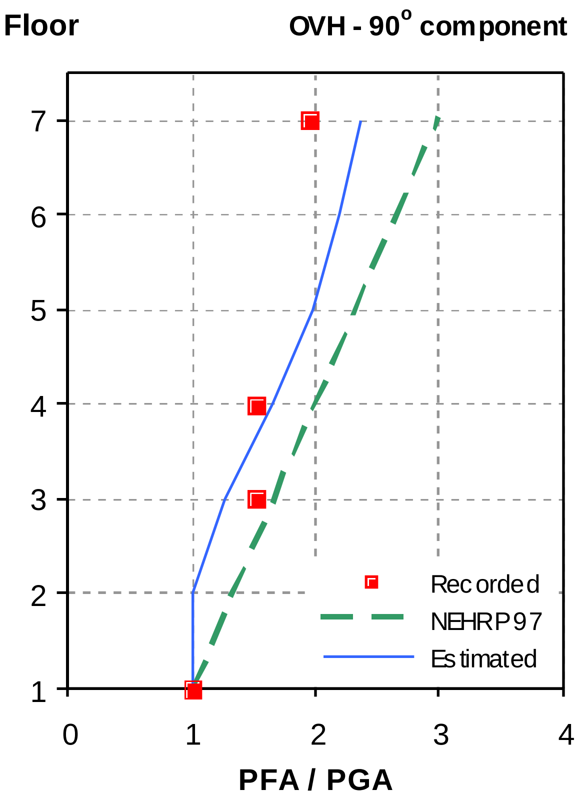

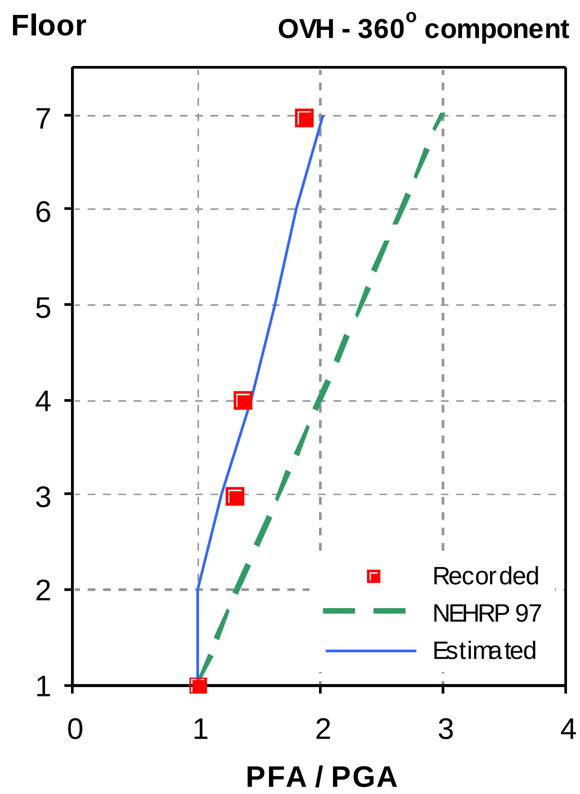

Challenges in Predicting EDP's

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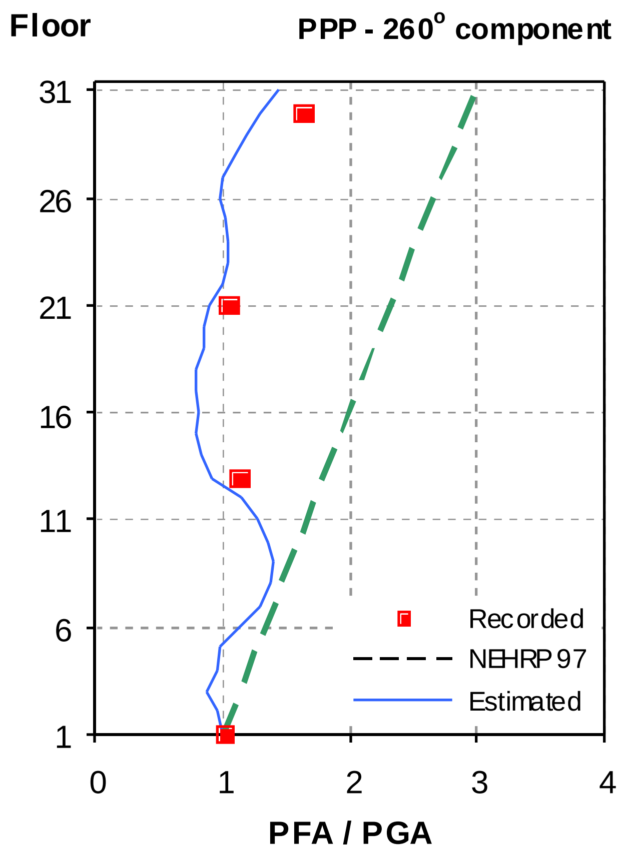

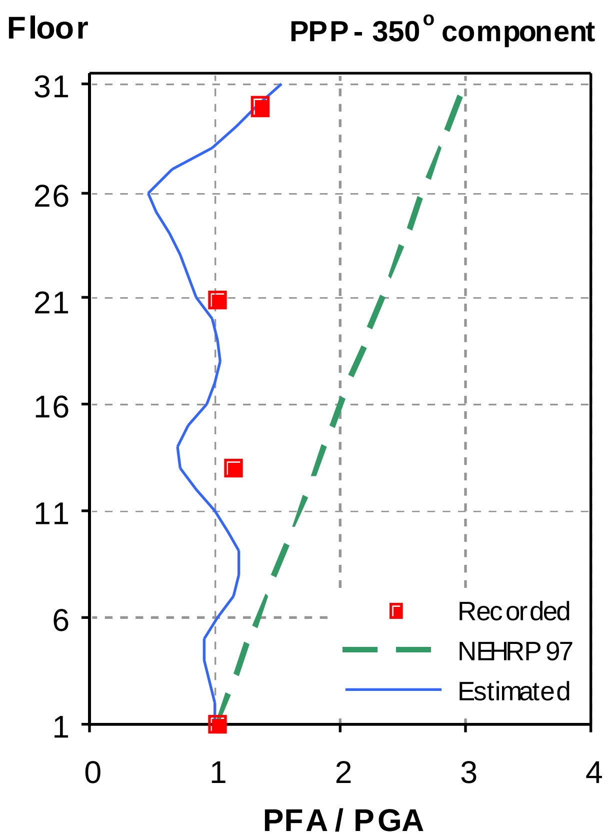

Challenges in Predicting EDP's

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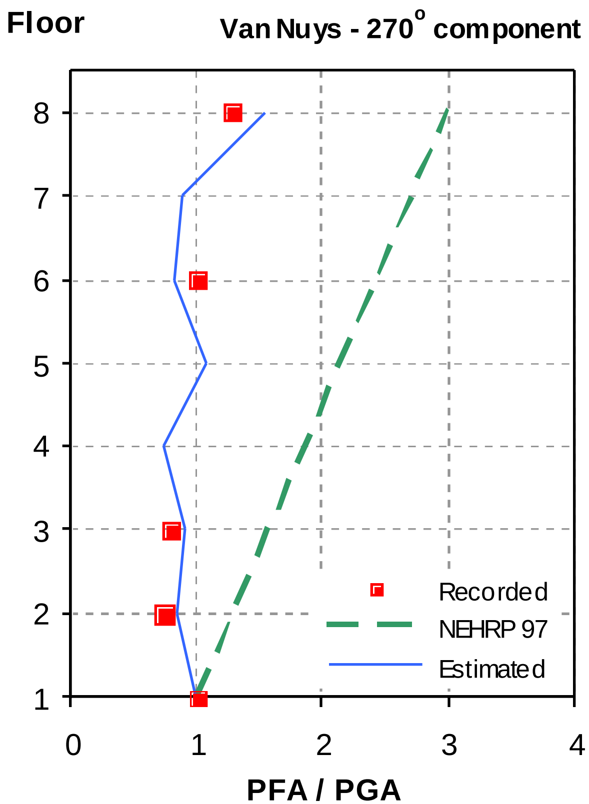

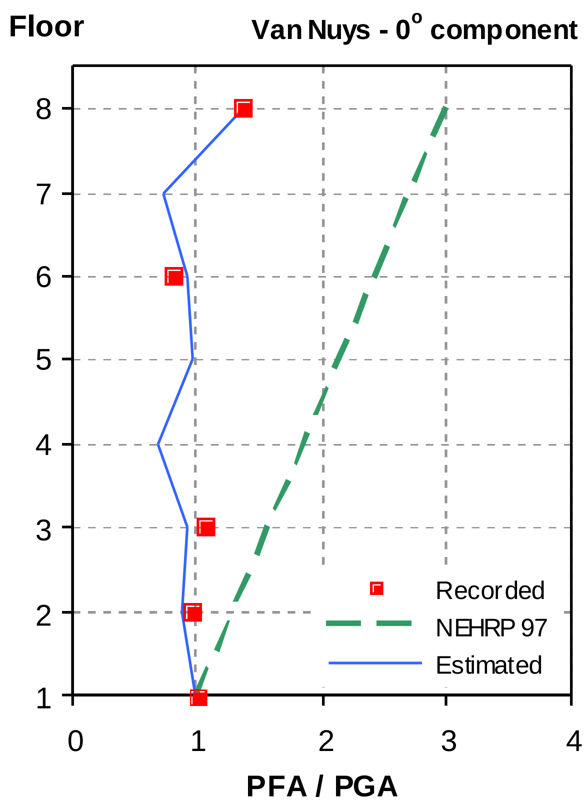

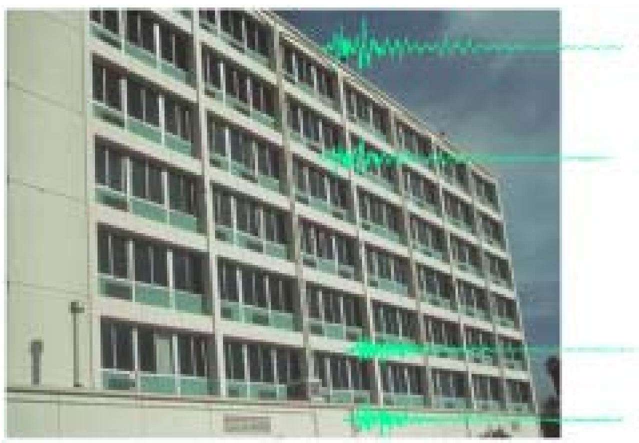

Challenges in Predicting EDP's

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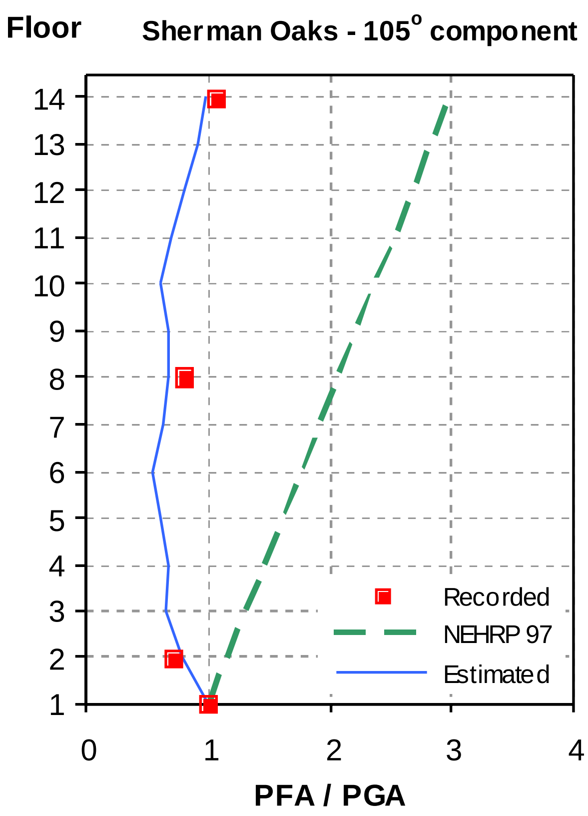
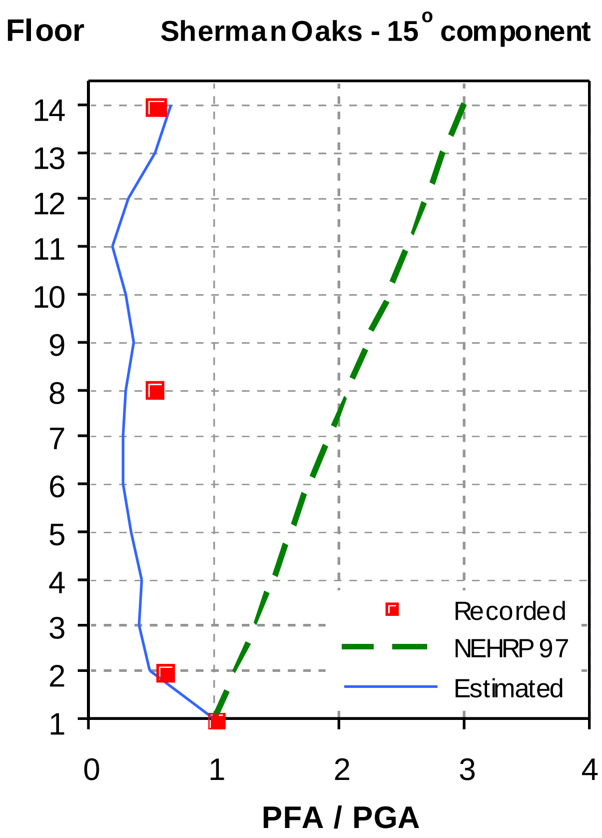




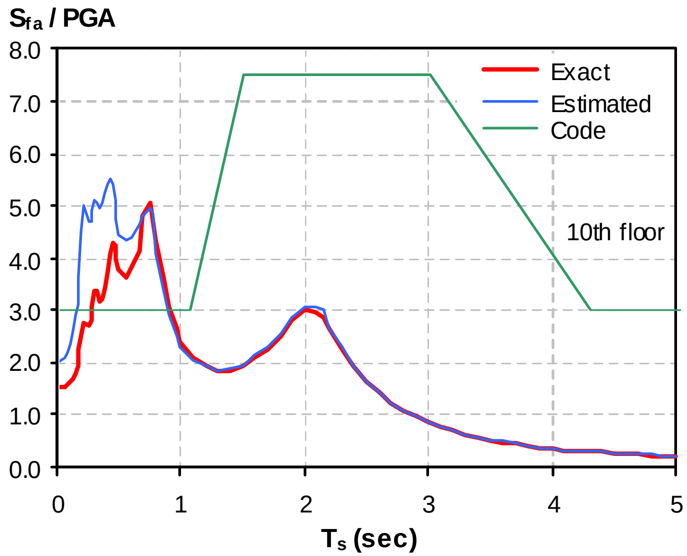
PEER

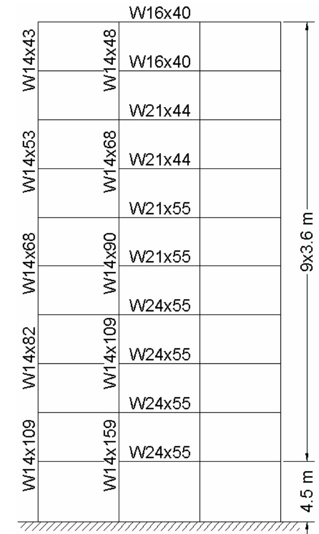
Challenges in Predicting EDP's

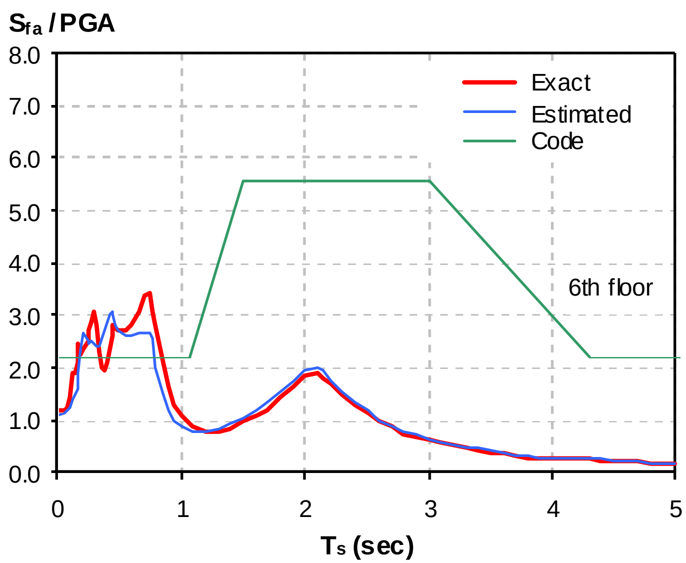
- Ground Motion

- Fundamental period of vibration and lateral resisting system

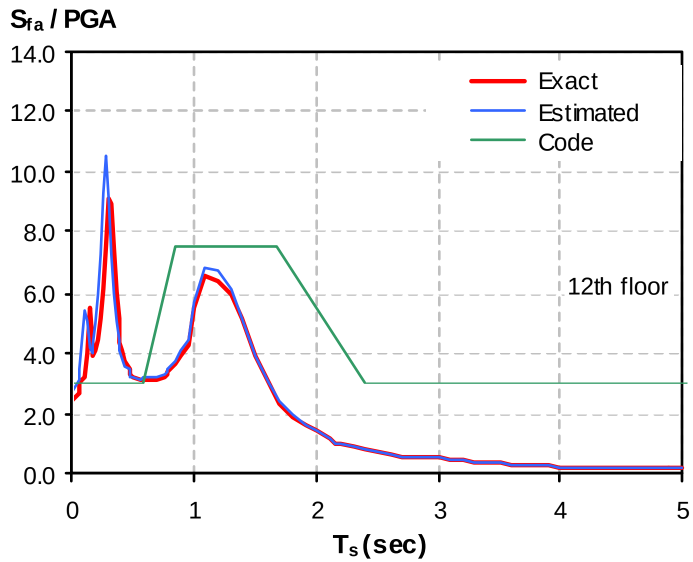
Challenges in Predicting EDP's

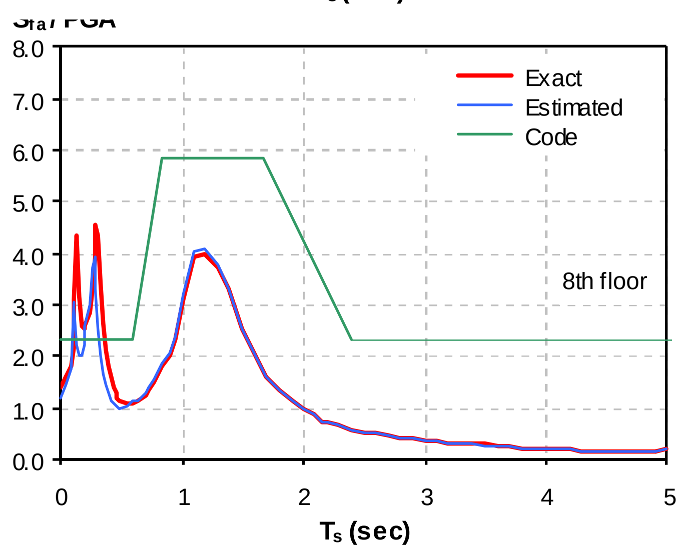


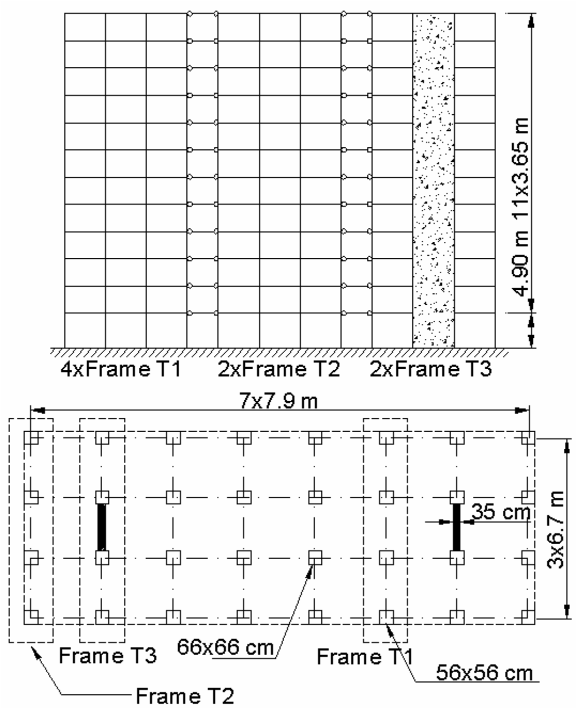




Challenges in Predicting EDP's







Challenge No. 7

Prediction of damage to nonstructural components for a given EDP

EDP → DM

P(DM | EDP)

Component Vulnerability Assessment : Nonstructural Components

Partitions

Define damage states for the component — Gather motion – damage pairs — Develop fragility functions

(1)

Light Cracking

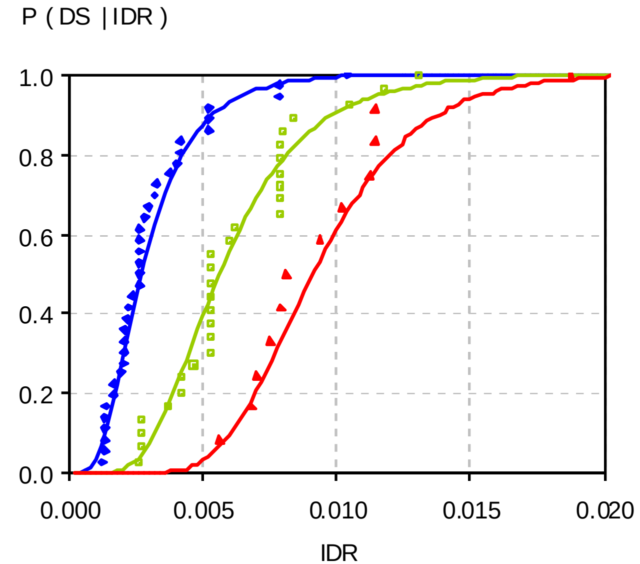
(2)

Severe Cracking

(3)

Damage to Frame

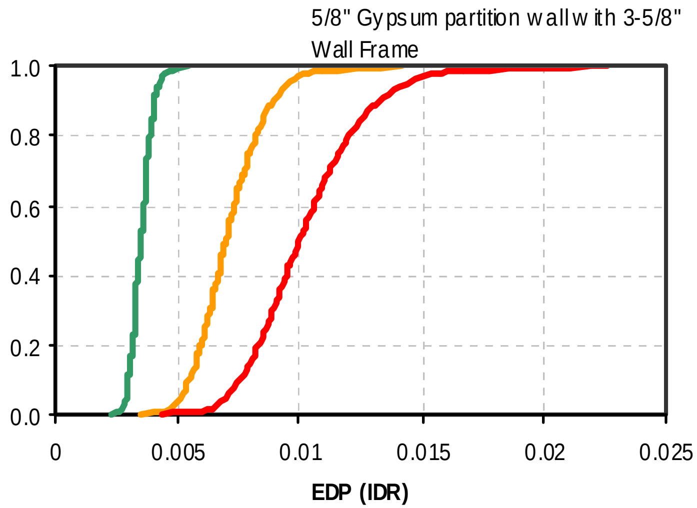
Specimen Name	DS_1	DS_2	DS_3
S1	0.0013	0.0025	0.0056
S2	0.0013	0.0026	0.0068
S3	0.0013	0.0026	0.0070
S4	0.0013	0.0026	0.0075
S5	0.0013	0.0037	0.0079
S6	0.0014	0.0042	0.0081
S7	0.0017	0.0042	0.0094
S8	0.0017	0.0046	0.0102
S9	0.0019	0.0052	0.0113
S10	0.0020	0.0052	0.0115
S11	0.0021	0.0052	0.0115
S12	0.0021	0.0052	0.0188



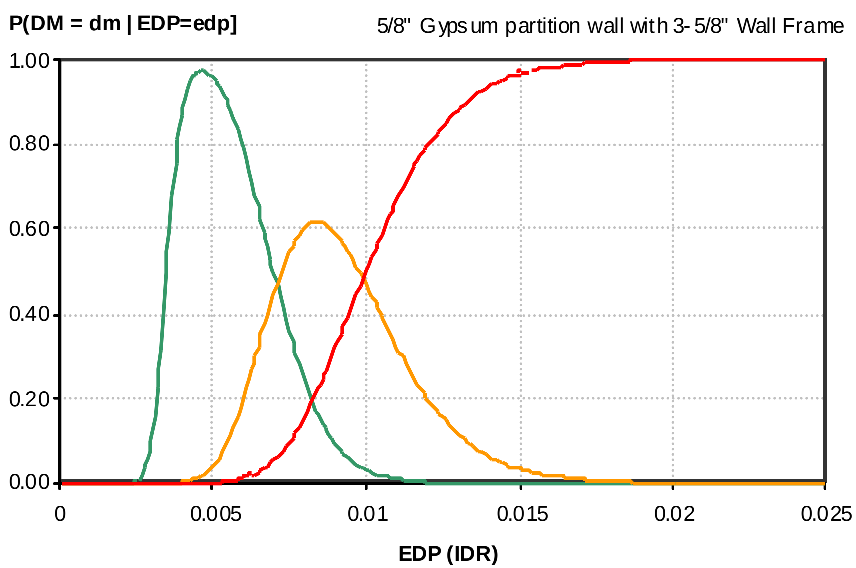
Taghavi and Miranda

Component Vulnerability Assessment :
Nonstructural Components

Fragility Functions



$$P(DM_j = dm_i \mid EDP_j = edp) = F_i - F_{i+1}$$



Challenges in establishing fragility of NSC's

Very little experimental data

Nuclear related and perhaps not relevant

Qualification test

Very little useful performance data

Why did it failed ?

At what EDP level did it failed ?

Why it did not fail ?

At what EDP level did it perform well ?

Challenges in establishing fragility of NSC's

is helping here too !

UC Berkeley

UC Irvine

UC San Diego

Challenge No. 8

Attracting research dollars to this area

Attracting people to work in this area

Summary of challenges

Where are the challenges ?