Simpson Gumpertz & Heger Inc. Consulting Engineers

Building Engineering ■ Infrastructure and Special Structures ■ Construction Engineering

Potential of PBEE in the Selection and Comparative Performance of Structural Systems

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Craig CoMartin

Purpose of the Study

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Capabilities of Current Practice
How do Different Structural Systems Perform
When Evaluating both Drift and Acceleration

vs

Potential of PBEE
in Comparing Performance of Structural Systems

Framing Schemes Included in Comparative Study

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- Moment Frame
- Buckling Restrained Braced Frame
- Viscously Damped Frame
- Base Isolated Braced Frames

Project Overview

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- 3, 9 and 20 story SAC buildings designed using 1997 UBC
- BRB's - 45 Ksi yield level.
- Viscously damped moment frames designed for 75% of the base shear and the dampers designed to meet the 2% drift criteria with a 0.4 velocity coefficient.
- Base Isolated Braced Frame – 2.5 sec. period
- Focus today on 3 Story Building Results

Structural Systems

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- 4 Standard Code Compliant Designs
- Moment Frame, Buckling Restrained Braced Frame, Viscously Damped Frame and Base Isolated Brace Frame
- 2 Higher Performing (Lower Drift) “Hospital” Designs
- BRB with R=3.5 rather than 7
- Viscous damper force increased from 133K to 220K

3 Story SAC Buildings

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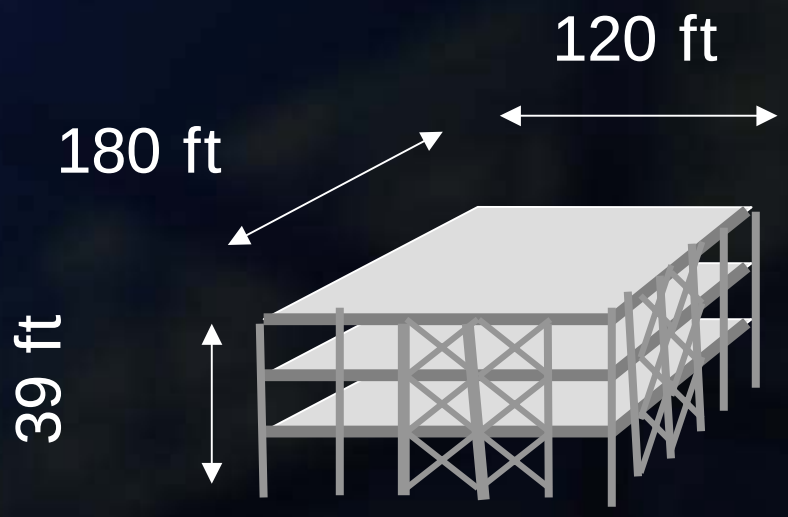
Building Description:

- 3 Story Building
- 6 x 4 - 30’ bays
- All Stories = 13’ tall



Earthquakes

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- The design earthquakes were:
  - 50% in 50 year – moderate event
  - 10% in 50 year – design event
  - 2% in 50 year – maximum credible event
  - Near fault events – within 10 miles of a fault
- Key results from 5 time histories for each event are averaged – SAC time histories were used.
- Focus on the results of the 50% and 10% in 50 year events.
- All seismic resisting elements were modeled with their non-linear properties using RAM-Perform

1st Key Performance Parameter

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- Inter-story Drift – key code design parameter
  - Impacts structural frame, building facade, piping and ductwork, partitions
  - 2% drift with 13 ft. story height is 3 inches of inter-story displacement

% Interstory Drift
3 Story - 10% in 50yr Event

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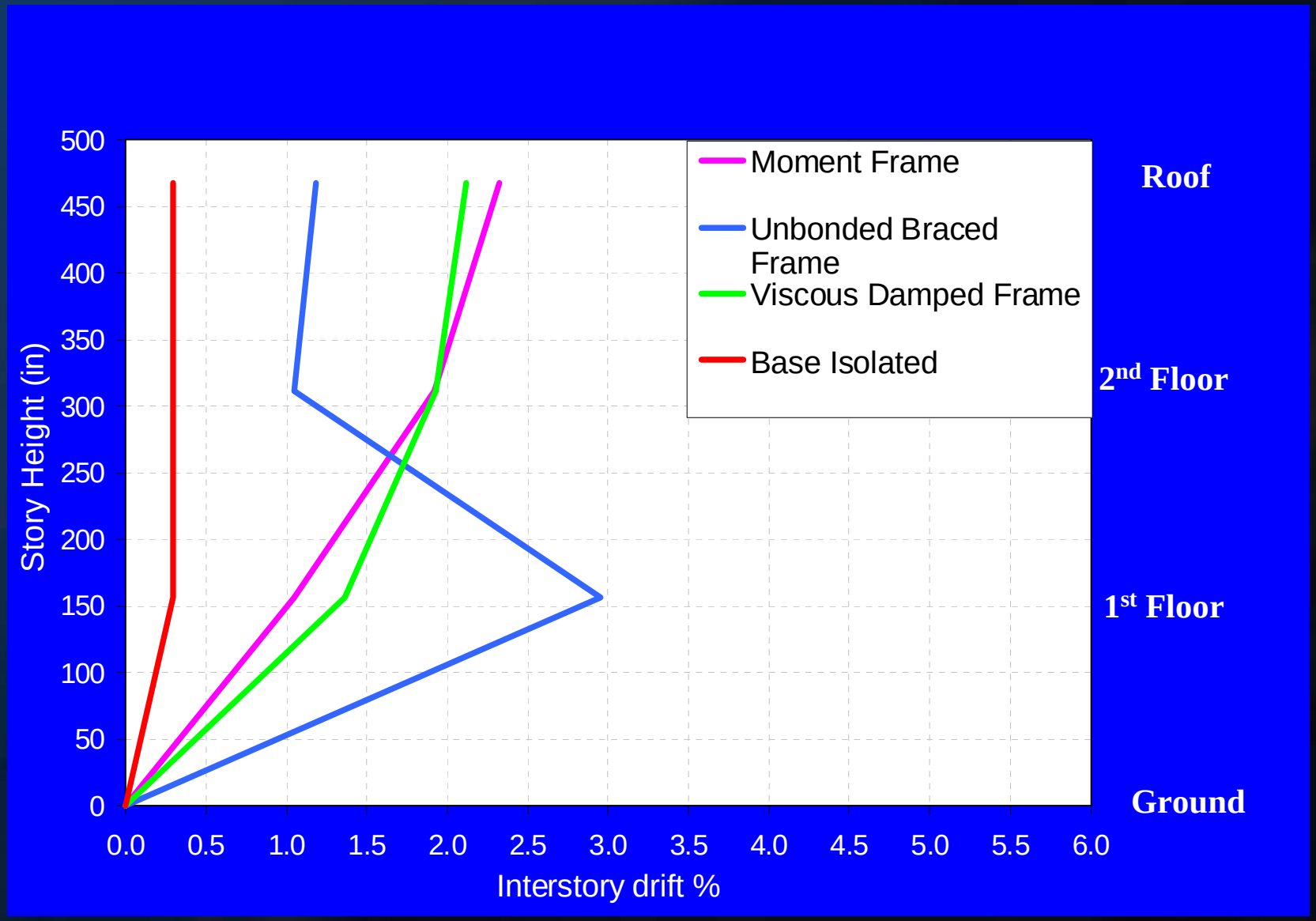

% Interstory Drift including Mean of 3 Floors
3 Story - 10% in 50yr Event

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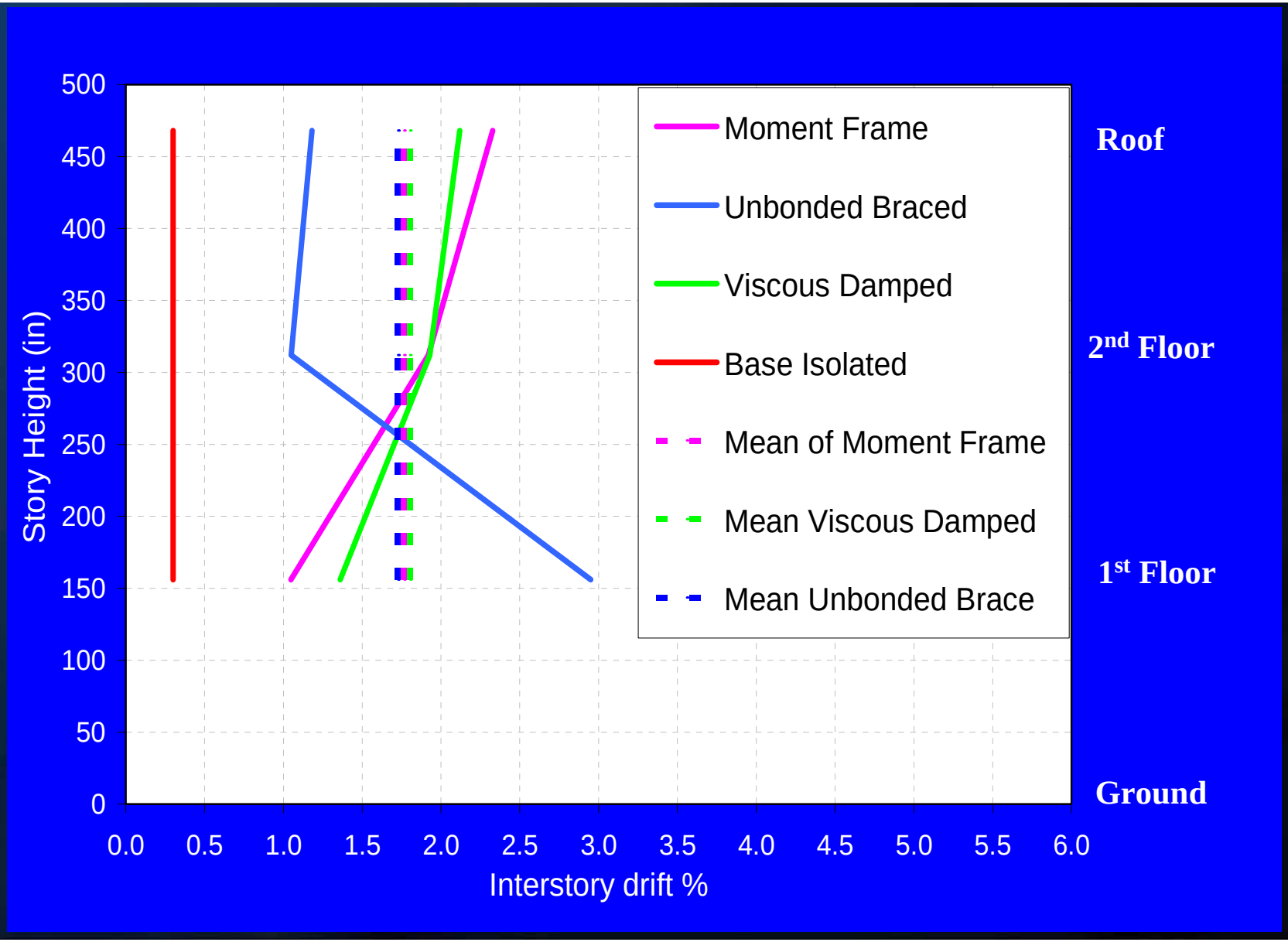

Normalized Mean Interstory Drift
3 Story - Design E/Q (10% in 50 Year Event)

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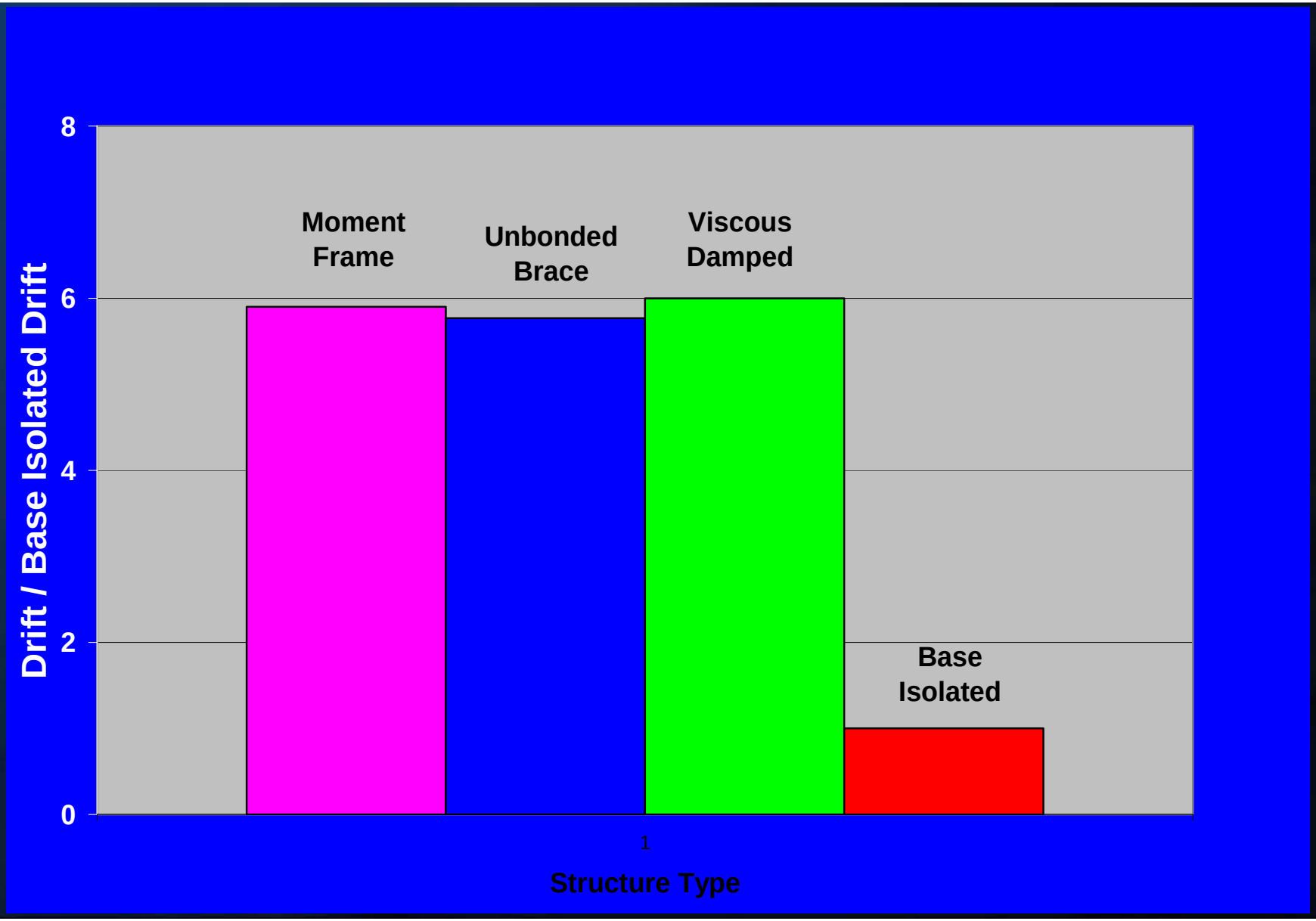

2nd Key Performance Parameter

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- Peak floor accelerations and floor response spectra – not required by code and rarely evaluated in the design process
  - Impacts contents, mechanical and electrical equipment, elevators and ceilings and lights.

Peak Floor Acceleration (ZPA)
Damage to Rigid Contents and MEP

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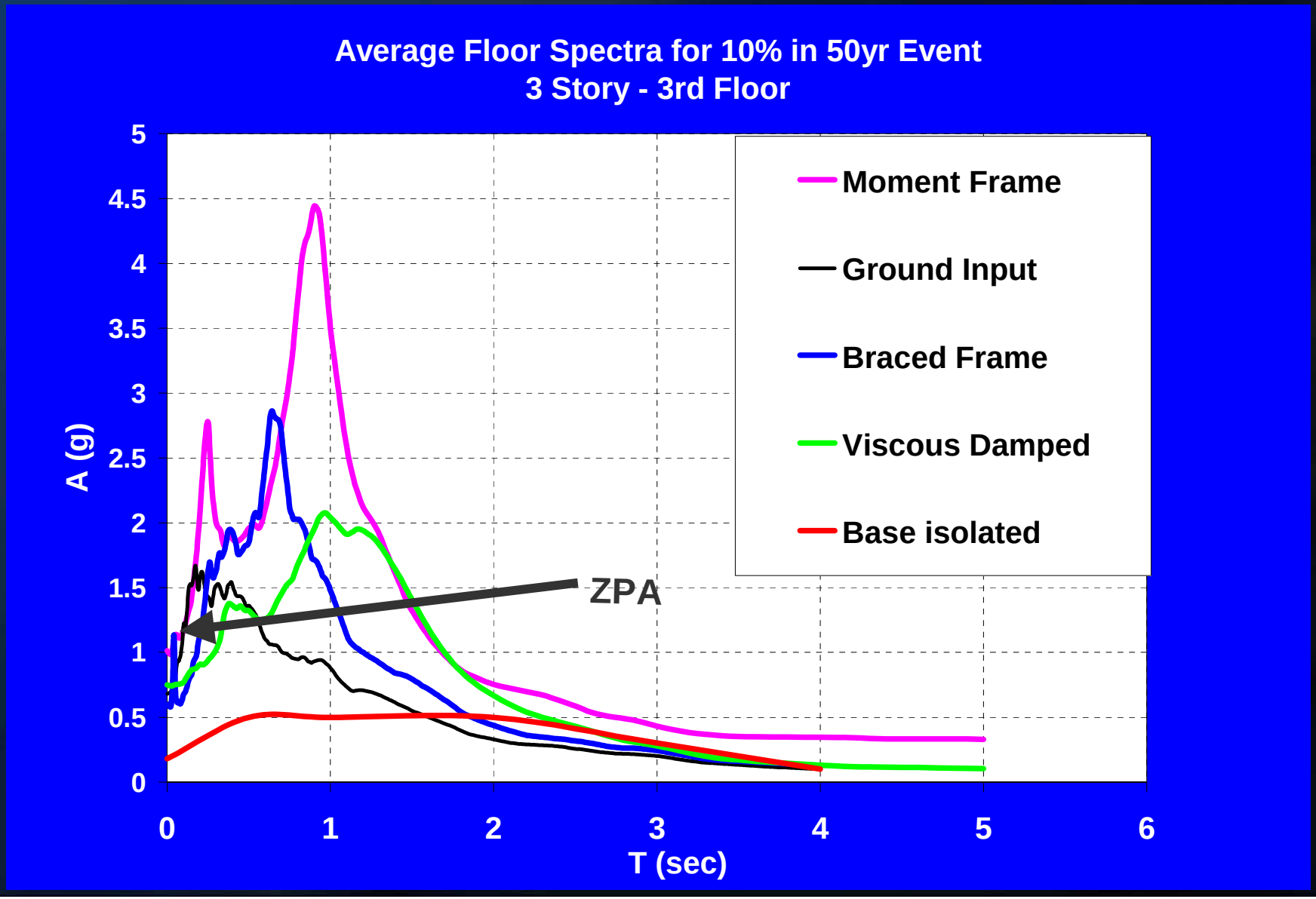

Average Peak Floor Acceleration (ZPA)
3 Story - 10% in 50yr Event

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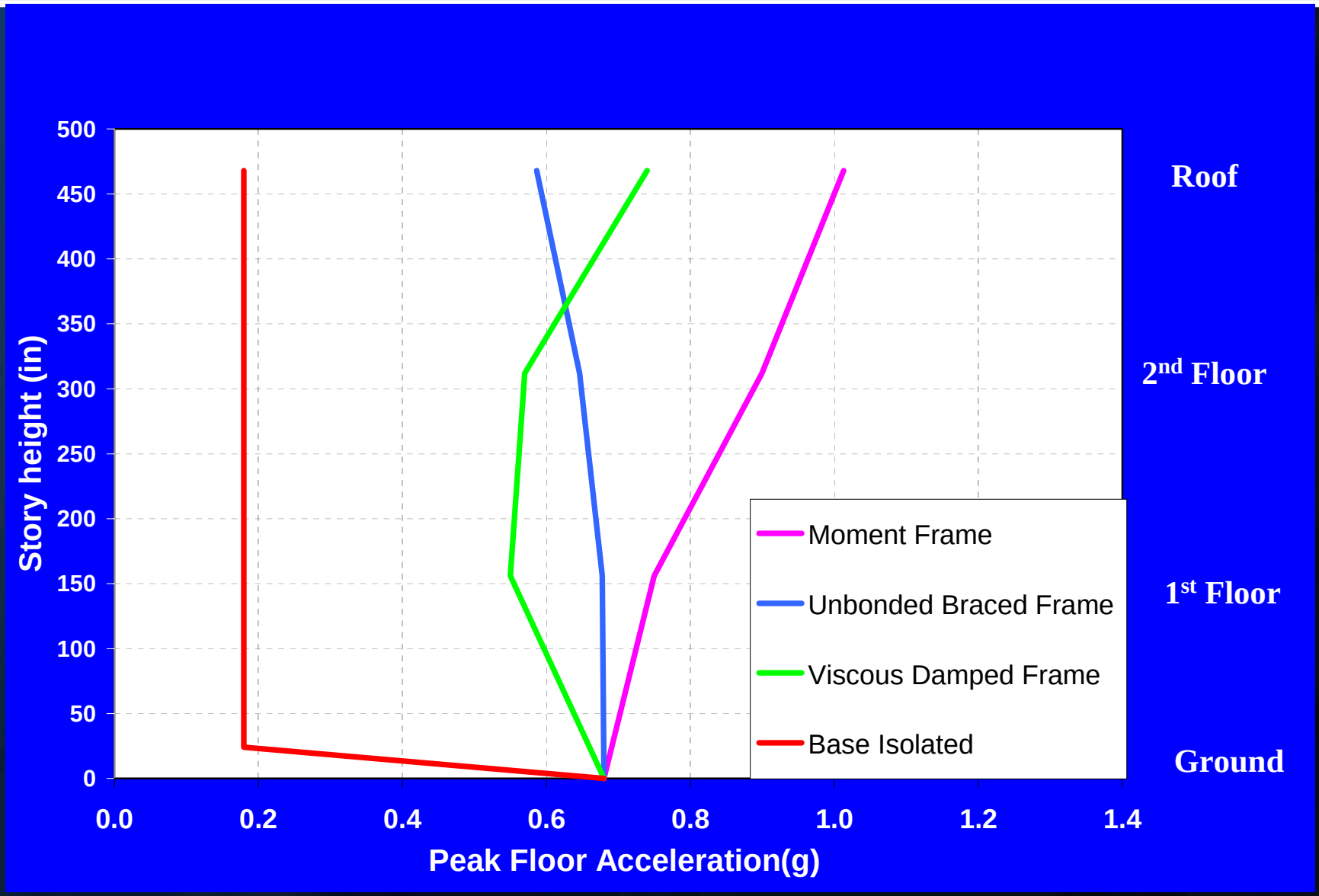

Normalized Mean Peak Floor Acceleration
3 Story - Design E/Q (10% in 50 Year Event)

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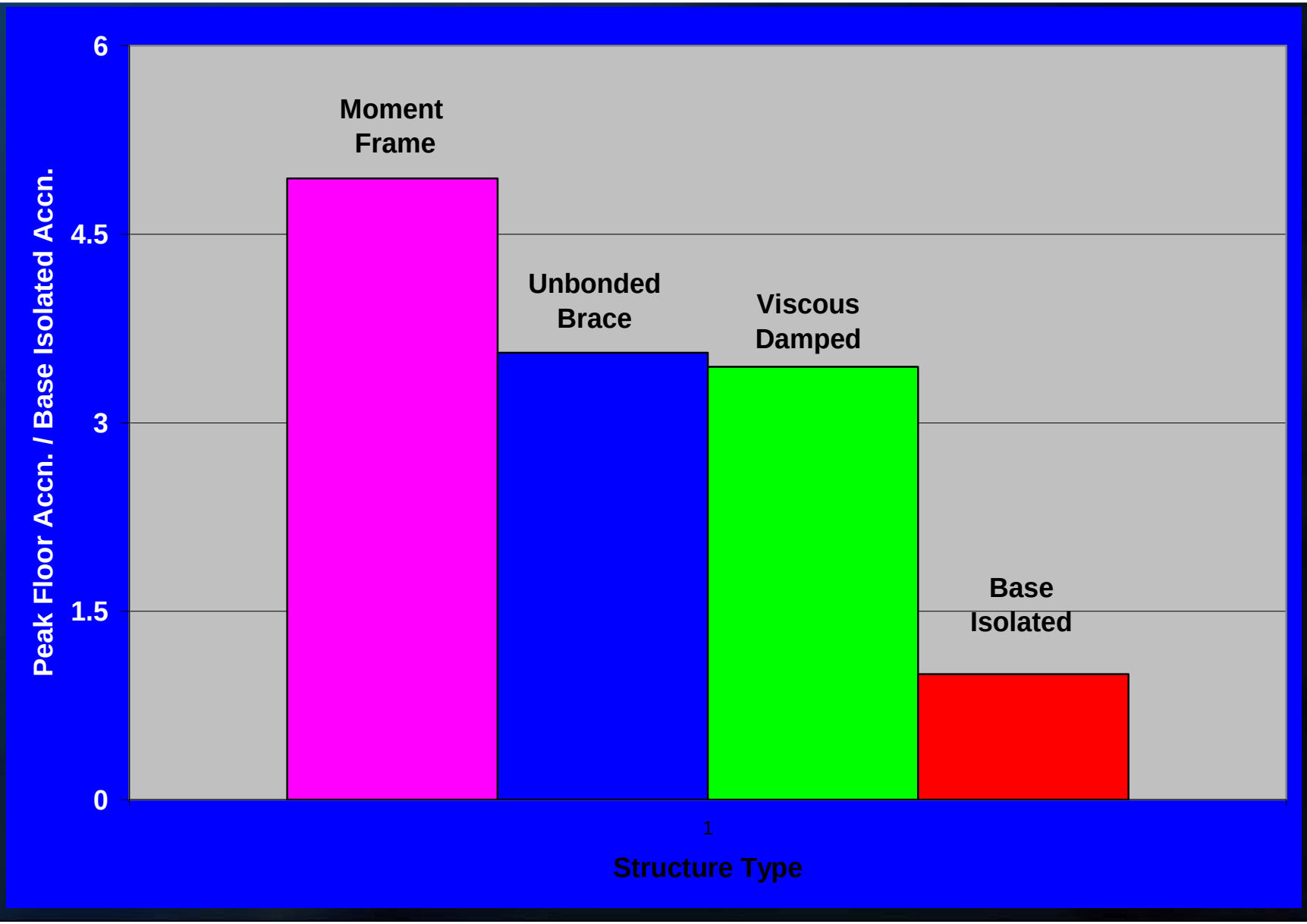

Peak of Spectra or Average Over a Period Range of Floor Spectra - Damage to Flexible Contents and MEP

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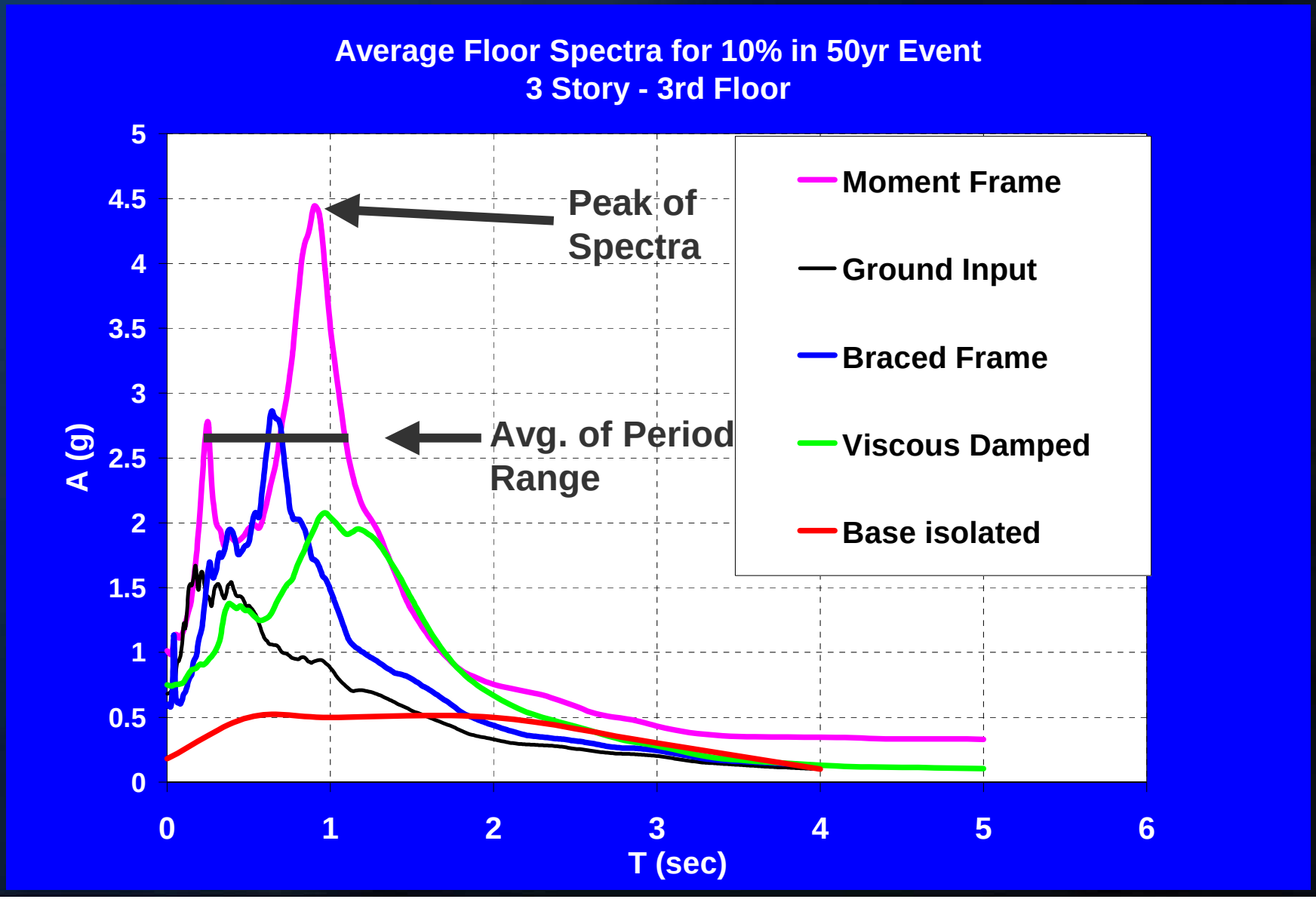

Normalized Peak Floor Spectral Acceleration
3 Story - Design E/Q (10% in 50 Year Event)

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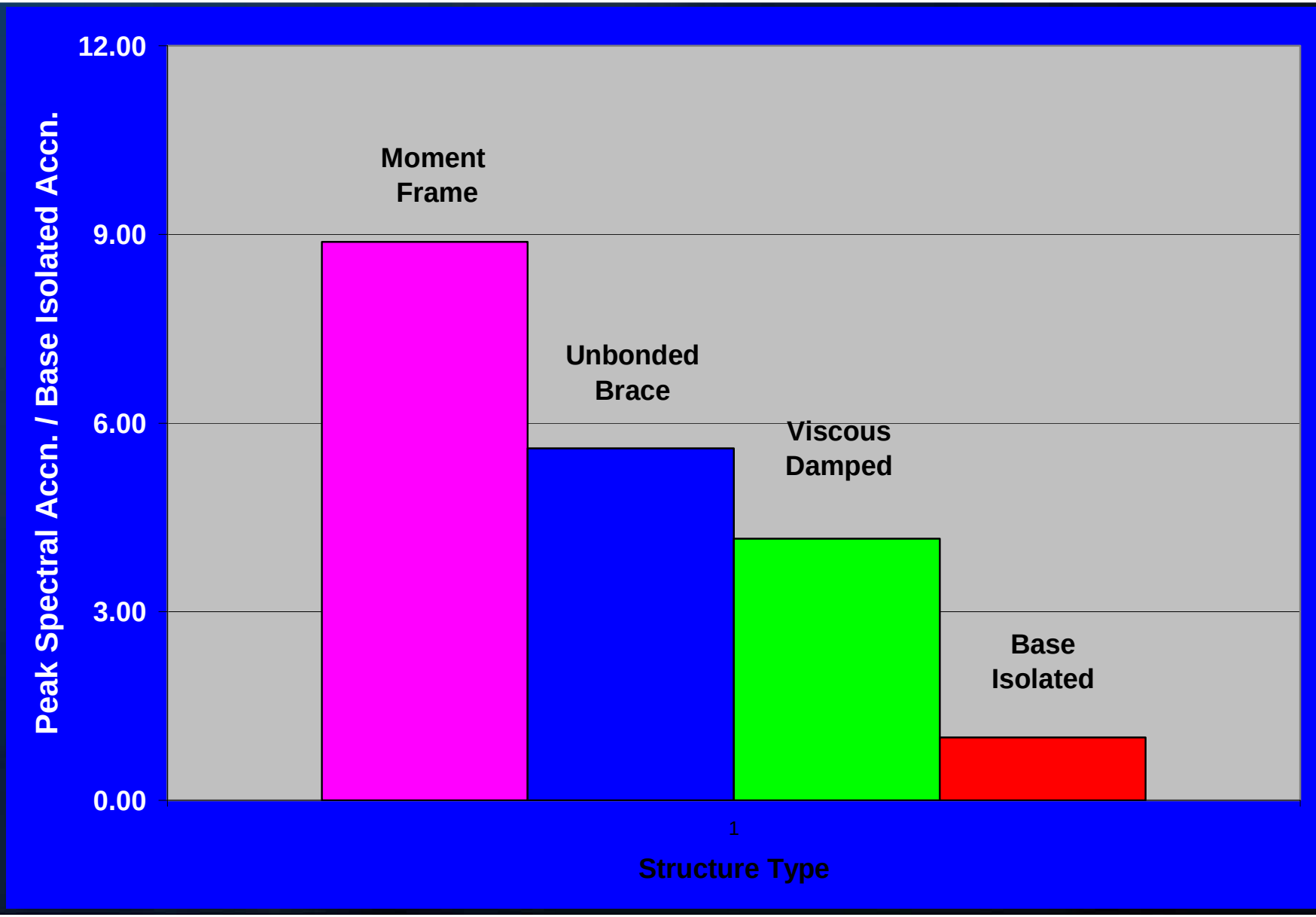

Comparison of Improved Drift Performance
Higher Performance

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- BRB – reduce the R-Factor from 7 to 3.5

- Viscously damped frame – increase damper force from 133 K to 220 K

Normalized Mean Interstory Drift
3 Story - 10% in 50 Year Event

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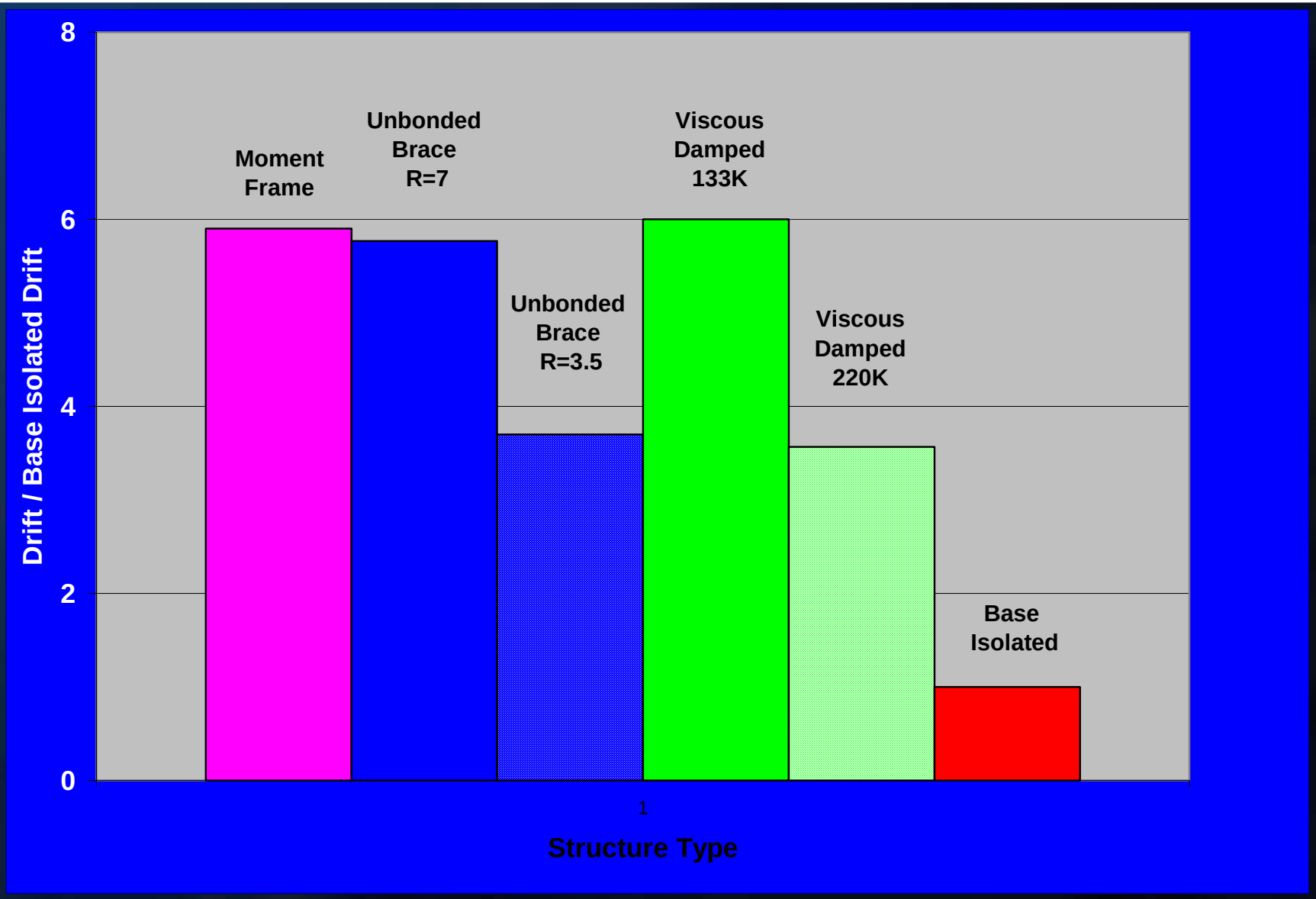

Normalized Peak of the Floor Response Spectra
3 Story - 10% in 50 Year Event

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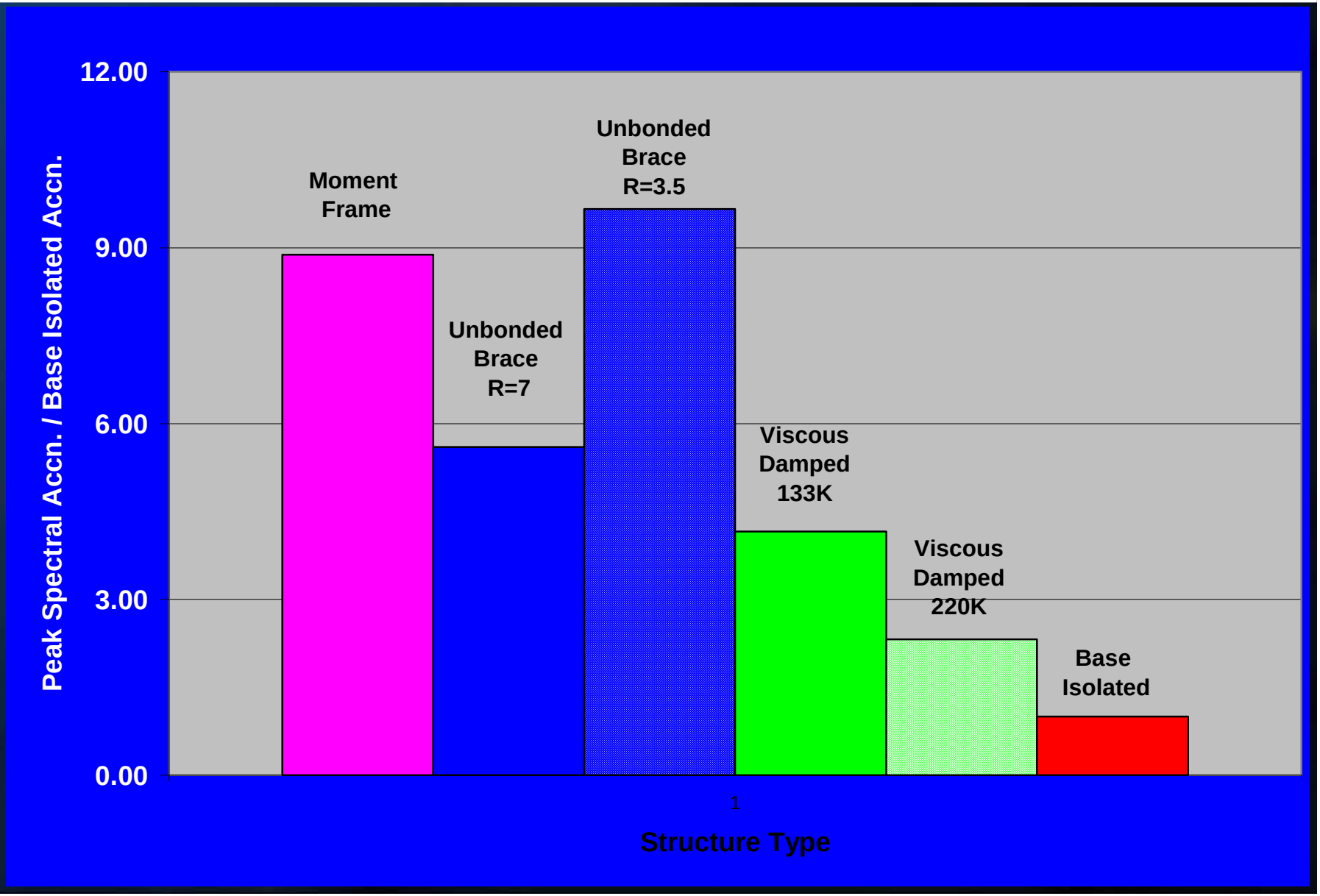
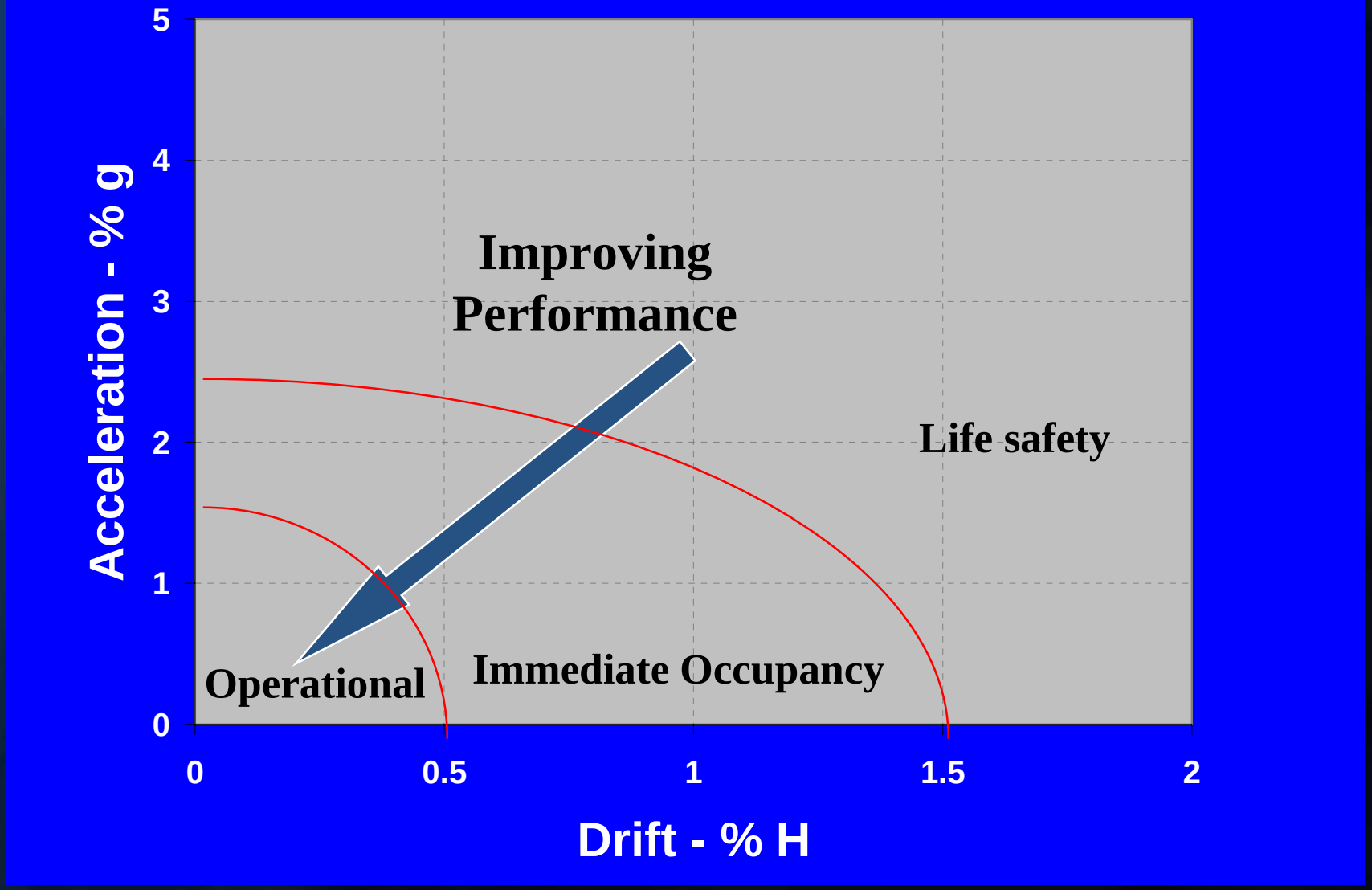


PBD – Compare Both Drift and Acceleration



Acceleration vs Drift
3 Story – Design Earthquake – SE Decision Event

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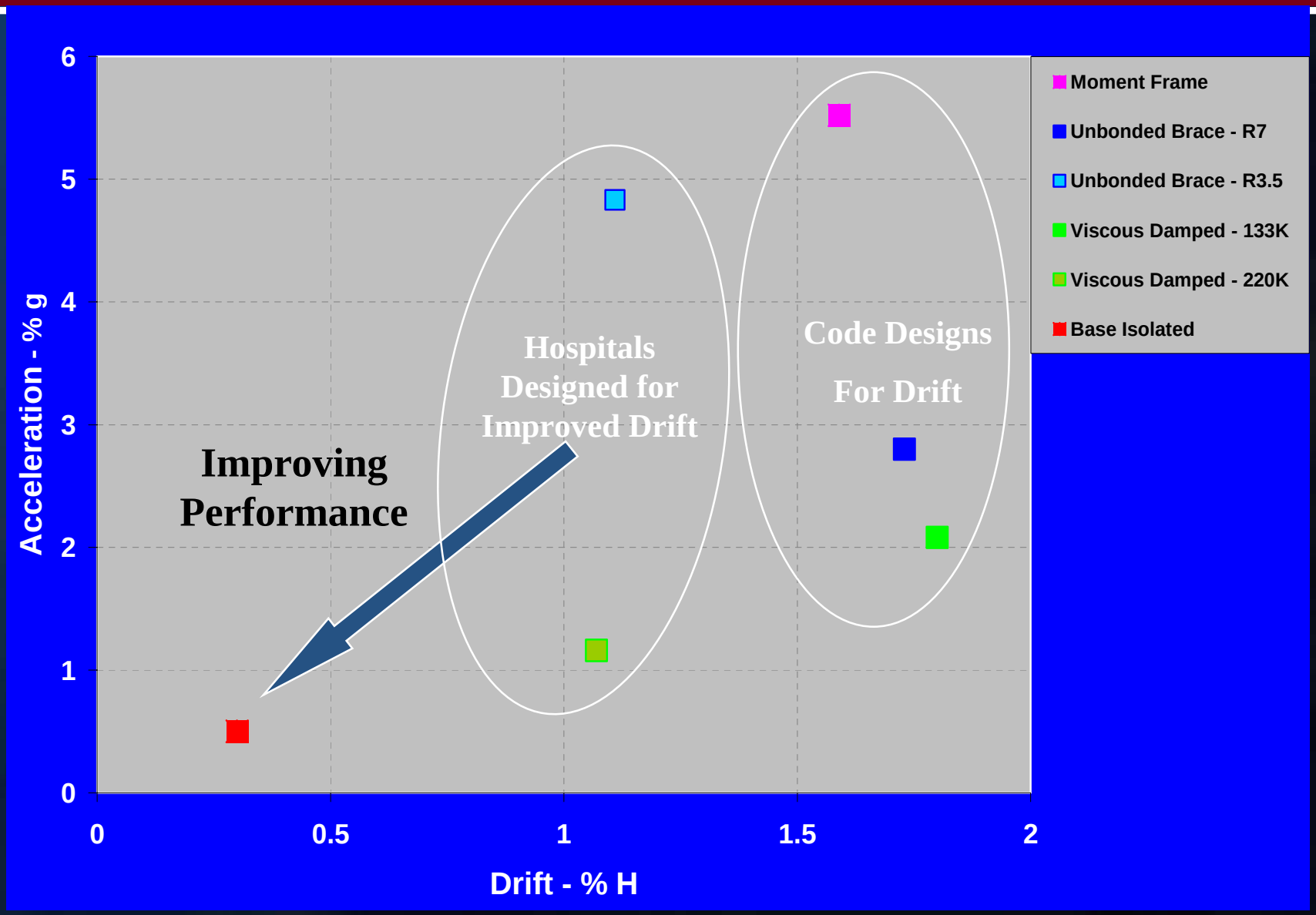

Acceleration vs Drift
3 Story – Design Earthquake

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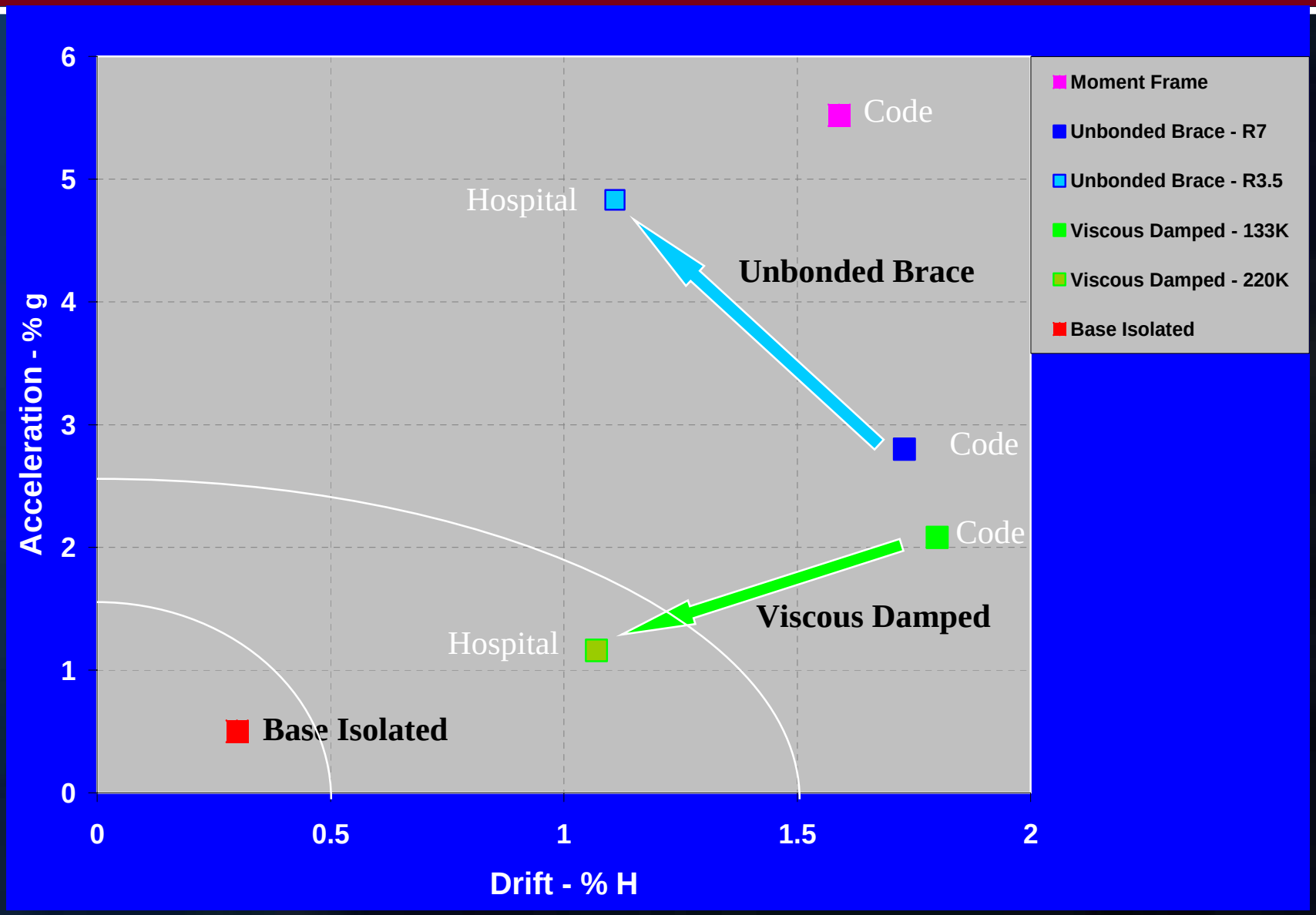

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Relative Costs – 3 Story Office Building			
Code Design	**Framing Cost $ / sq. ft.**	**Total Cost $ / sq. ft.**	**Increase Cost Over MF**
Moment Frame	$19.60	$100.00	Baseline
Viscous Damped	$20.20	$100.60	0.6%
Buckling Restrained R=7	$18.50	$98.90	- 1.1%
Base Isolated	$28.90	$109.30	9.3%
Concentric Braced	$15.90	$96.30	- 3.7%
Improved Drift Performance			
Viscous damped	$21.00	$101.40	1.4%
Buckling Restrained R=3.5	$19.30	$99.70	- 0.3%

Note: A base isolated building is an additional $39 / sq. ft. of plan area or $13 / sq. ft. on a concentric braced frame.

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Relative Costs – 3 Story Higher Performance			
Code Design	**Framing Cost $ / sq. ft.**	**Total Cost $ / sq. ft.**	**Increase Cost Over MF**
Moment Frame	$27.10	$250.00	Baseline
Viscous Damped	$27.70	$250.60	0.2%
Buckling Restrained R=7	$26.00	$248.90	- 0.44%
Base Isolated	$39.00	$261.90	4.7%
Concentric Braced	$23.40	$246.30	- 1.5%
Improved Drift Performance			
Viscous damped	$28.50	$251.40	0.56%
Buckling Restrained R=3.5	$26.80	$249.70	- 0.1%

Note: Base isolation cost is $39 / sq. ft. of plan area or an additional $13 / sq. ft for a concentric braced frame.

Potential of PEER & ATC 58 PBEE

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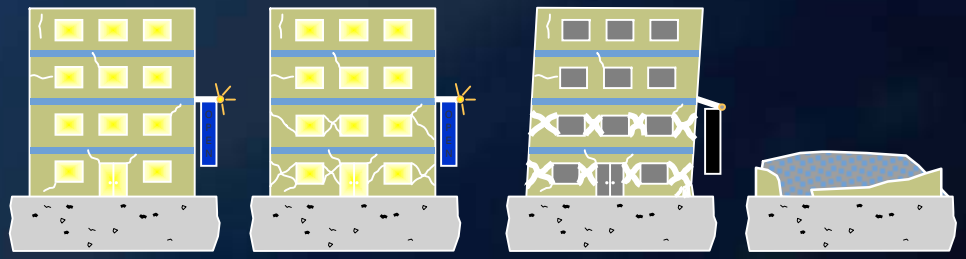
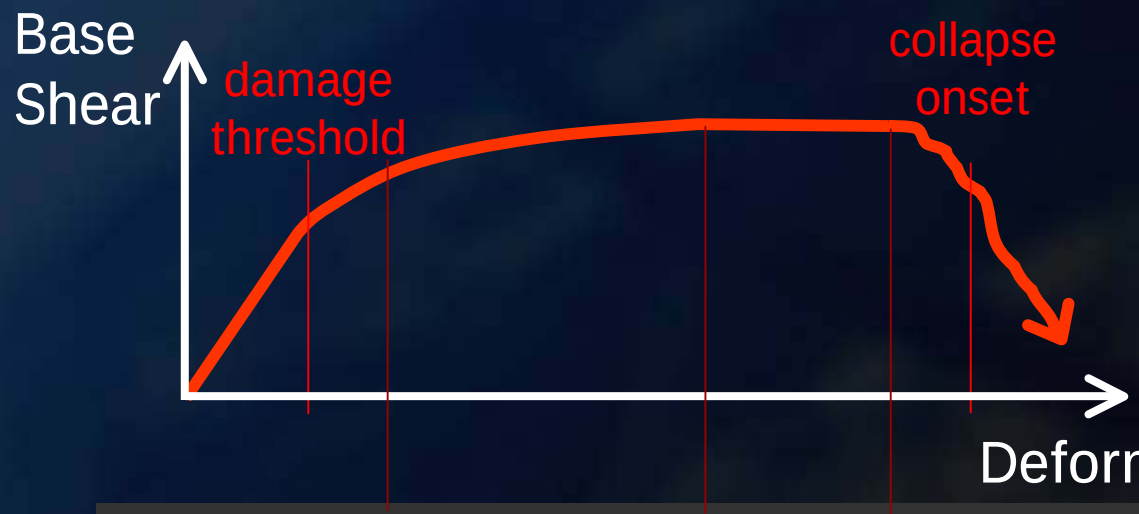
Conduct a PBEE study to assess the performance of the 6 structural systems using the data developed as part of ATC 58 and PEER project

Performance measures for decision-making





0		25%	50%	100%	$, % replacement
0.0	0.0001	0.001	0.01	0.25	Casualty rate
0	1	7	30	180	Downtime, days

Holmes, 2001

Office Building

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- Original damage data was based on the premise that the building was an office building ((70,000 sq. ft.) with a computer center on 3rd floor - $13M building cost - $25 /sq. ft. contents and total damage potential of $9M

Office Building – 10% / 50 Years
Code Designs

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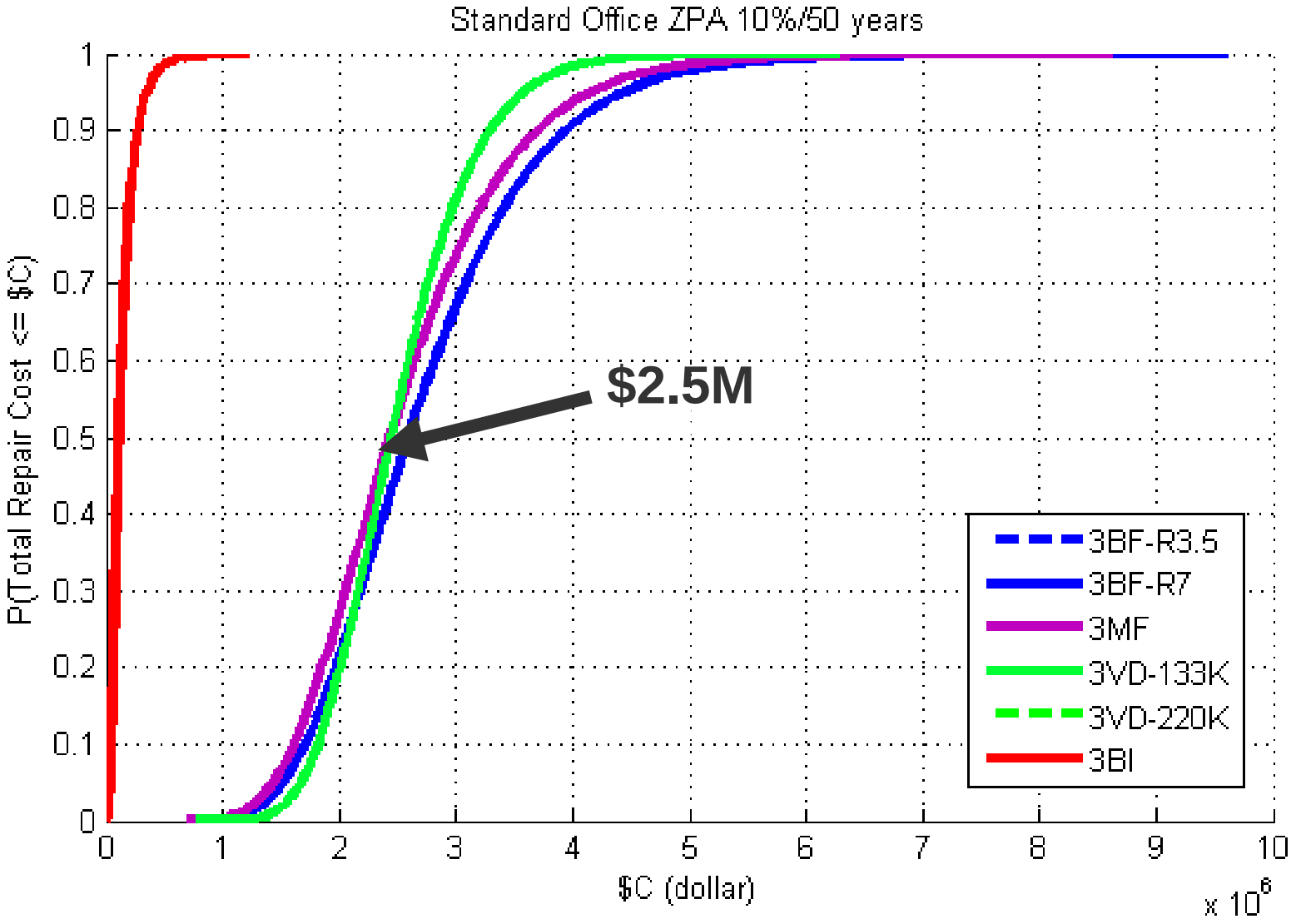

Office Building – 50% / 50 Years
Code Designs

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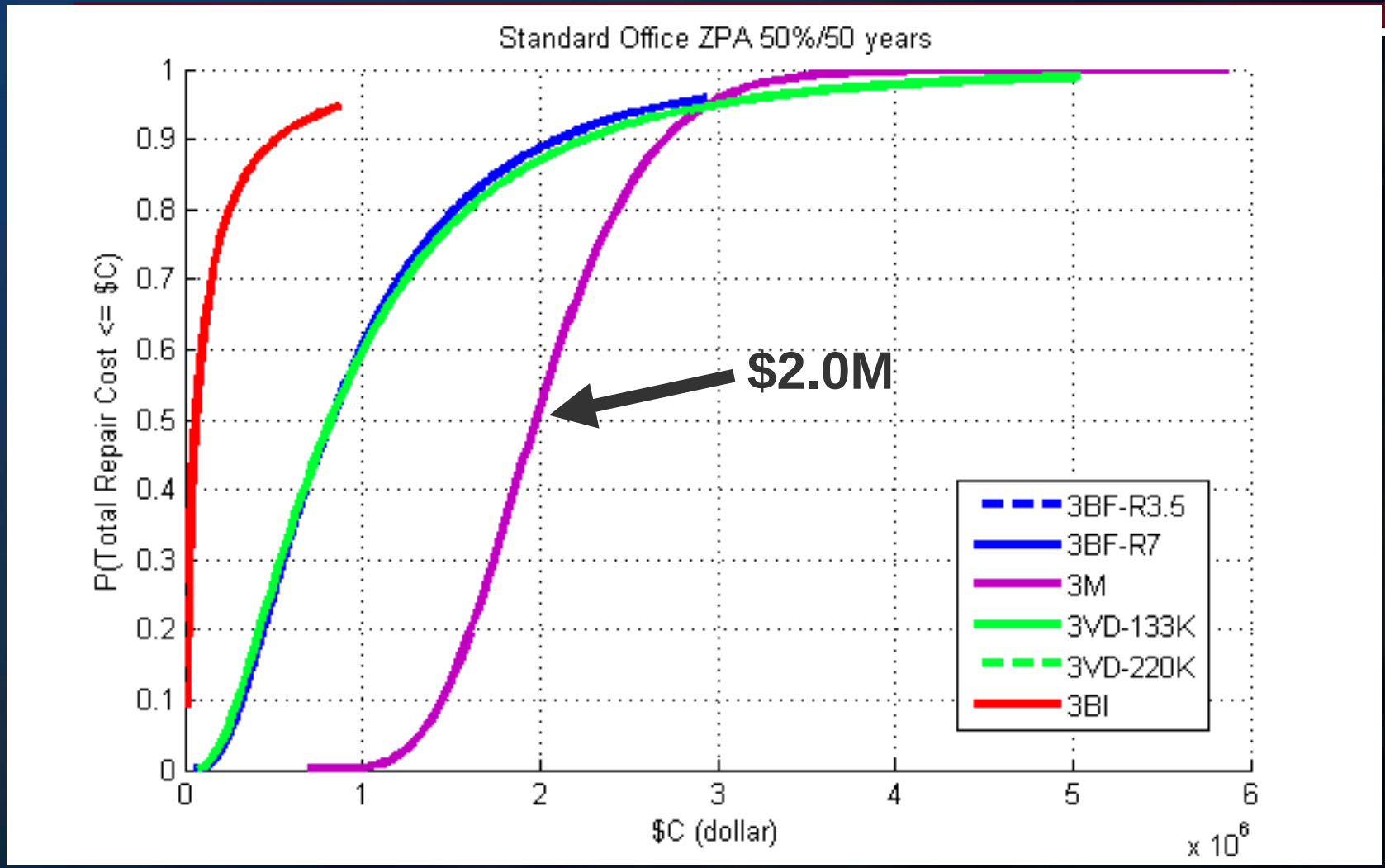

Office Building – 10% / 50 Years
Code & Higher Performance Designs

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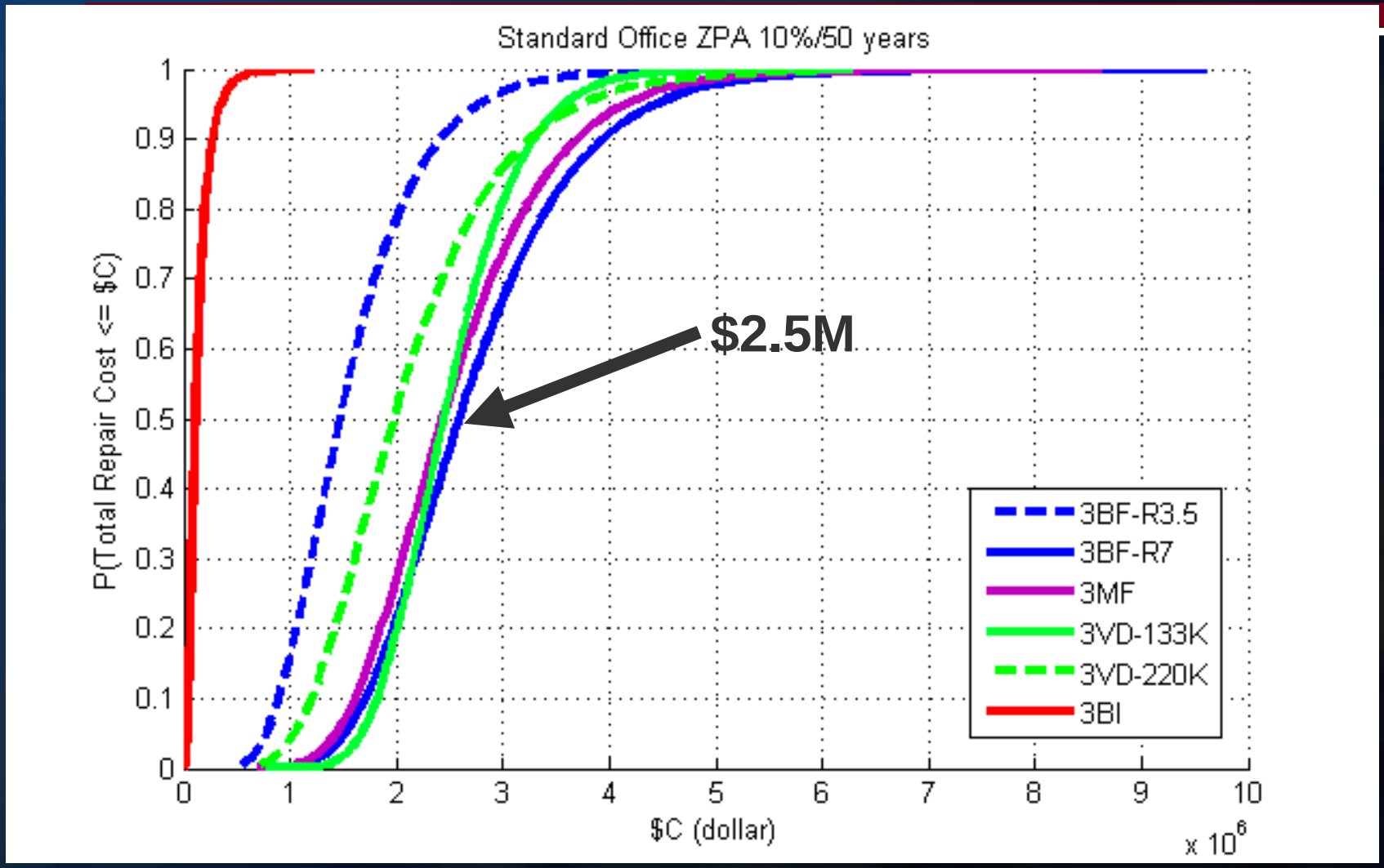

Office Building – 50% / 50 Years
Code & Higher Performance Designs

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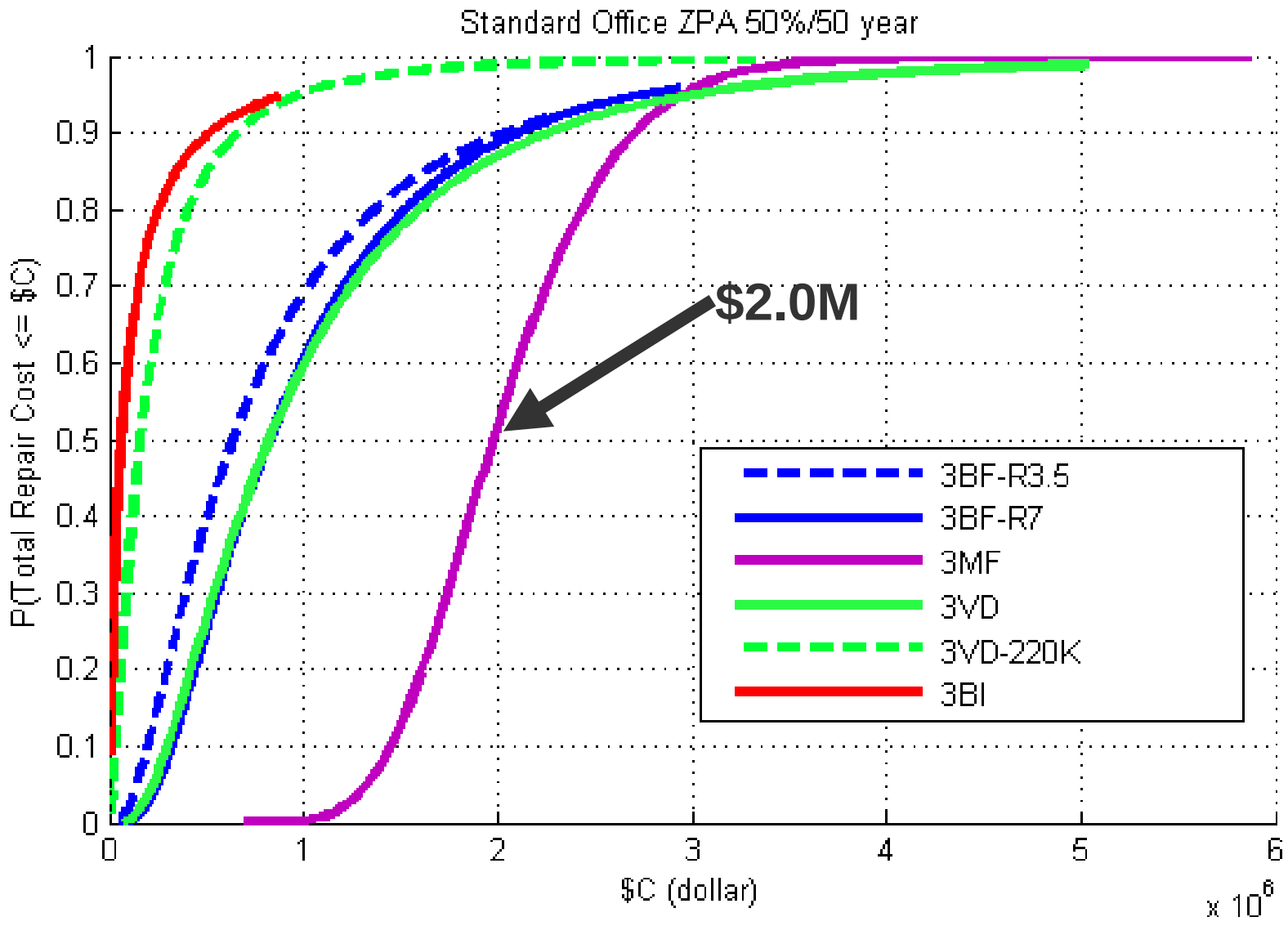

High Tech Manufacturing

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- Assumed the same office structure became a high tech manufacturing facility with $33M in contents. The only change was the potential damage to the contents – all other damage functions remained the same

- A basic limit was we did not change the structure damage states and repair costs so results are interesting from a comparative perspective but not accurate

Use of ZPA, Peak of Spectra or Average Over a Period Range of Floor Spectra for Acceleration Damage

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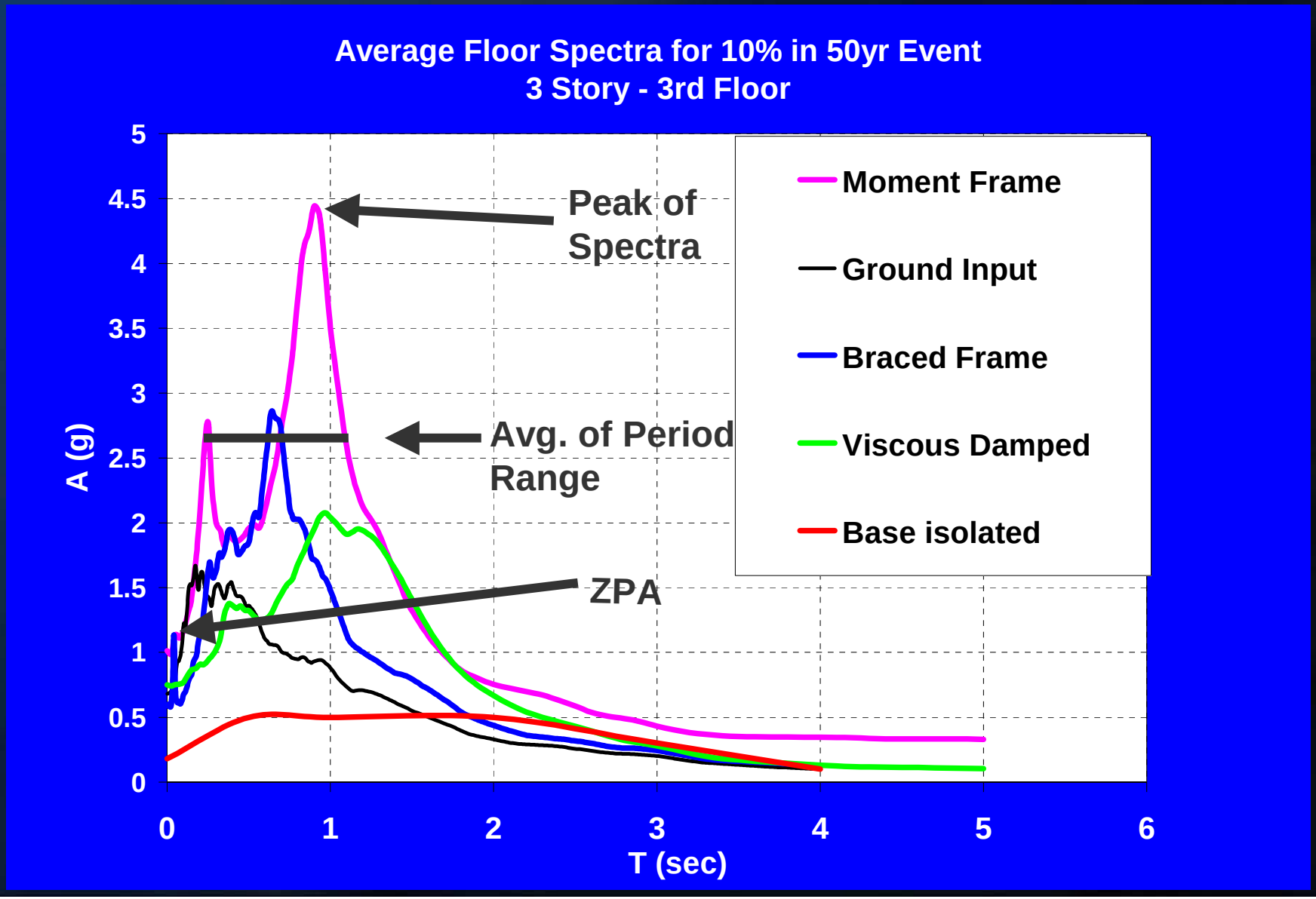

High Tech Manufacturing – 10% / 50 Years
Higher Performance Designs – ZPA

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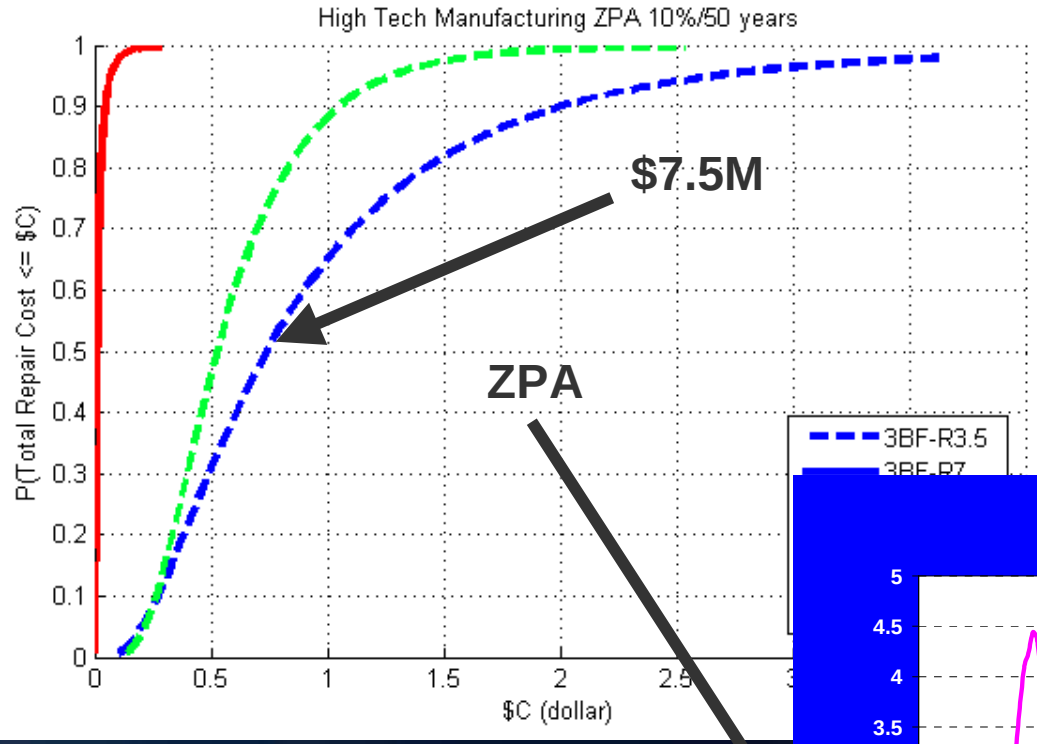
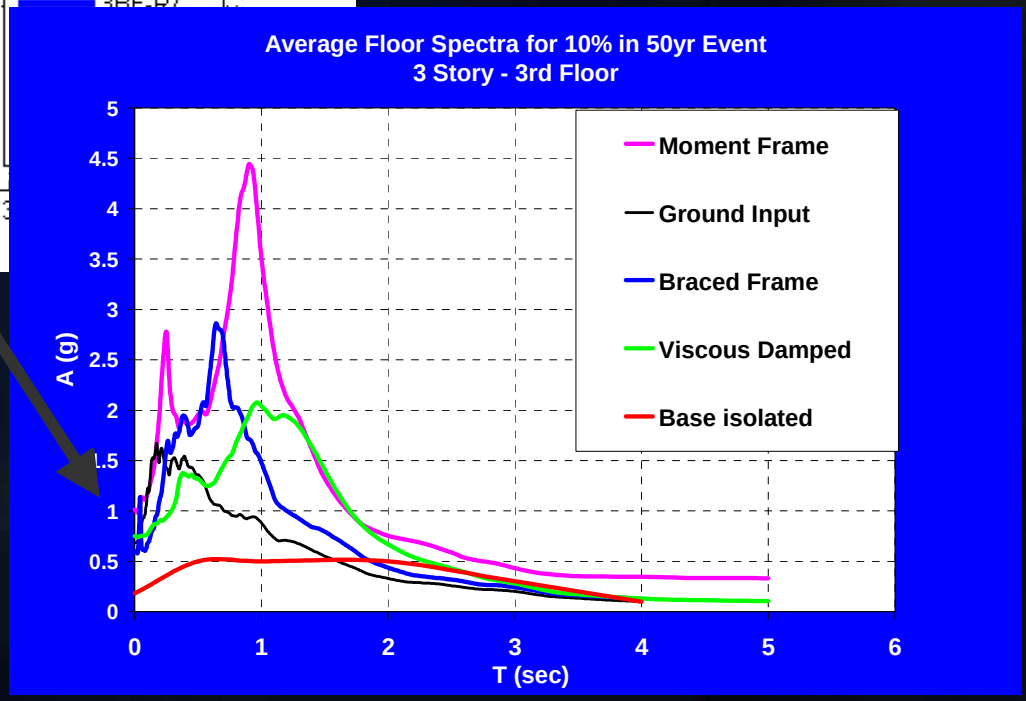


Office Building - $2.5M



High Tech Manufacturing – 10% / 50 Years
Higher Performance Designs – Peak Spectra

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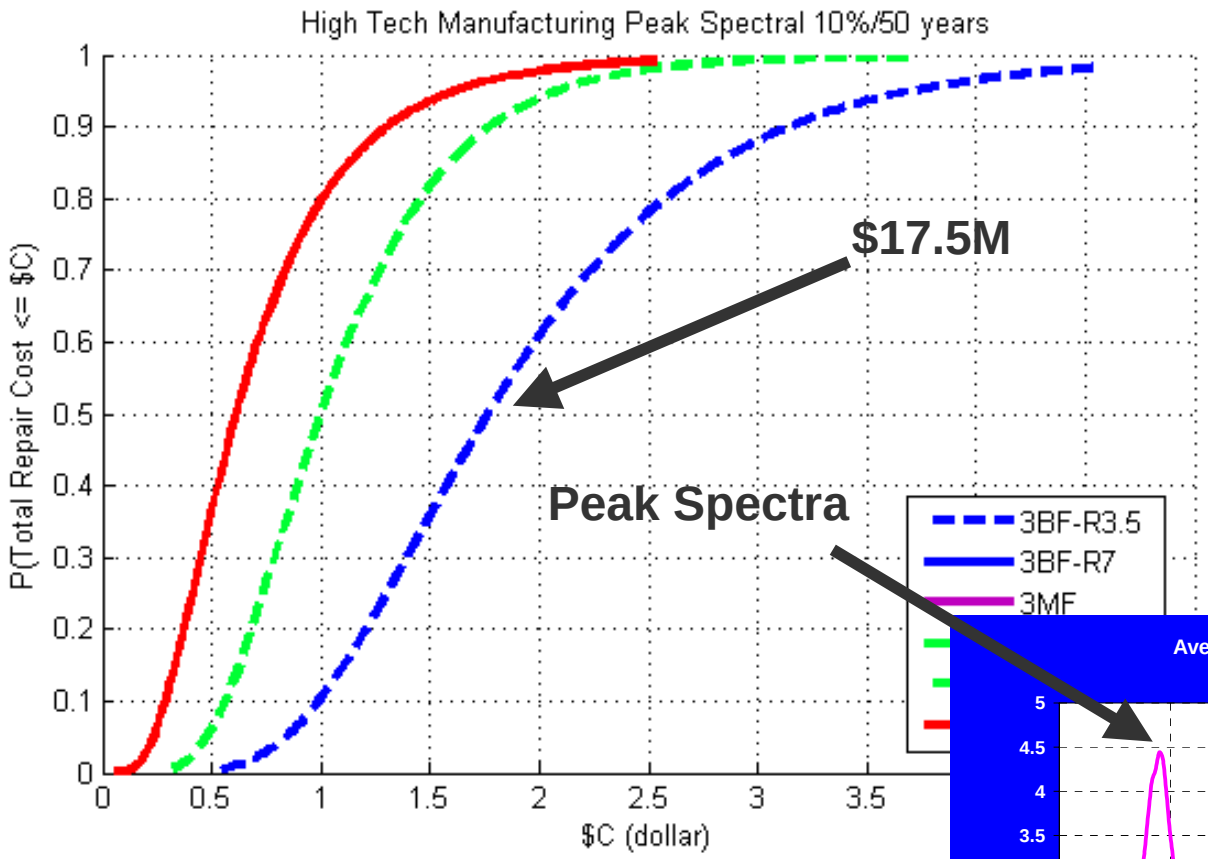
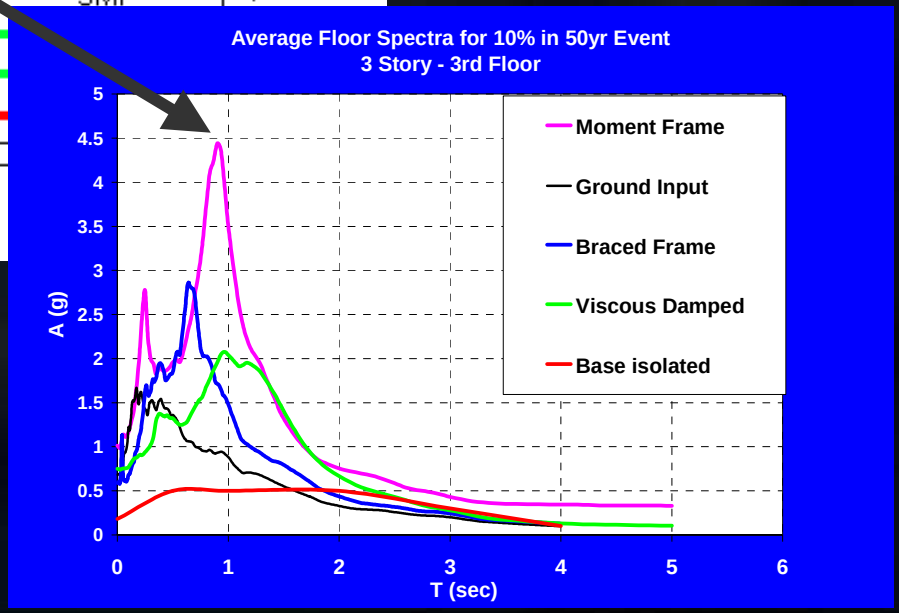


Office Building
$2.5M



Mean – ZPA & Peak
$12.5M

High Tech Manufacturing – 50% / 50 Years
Higher Performance Designs – ZPA

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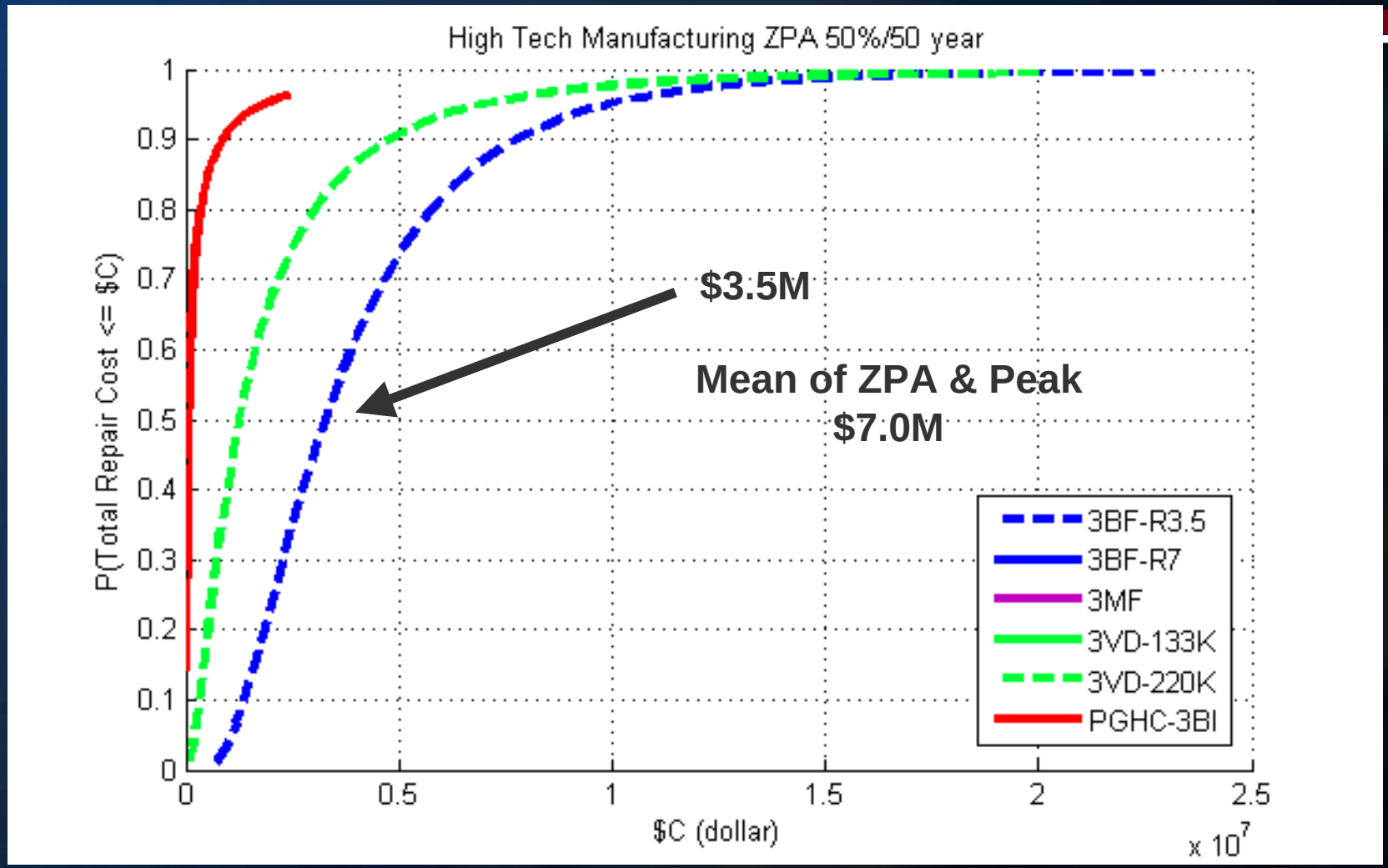


Various Expressions of Repair Costs

DV
DM
EDP
IM

$5.2M

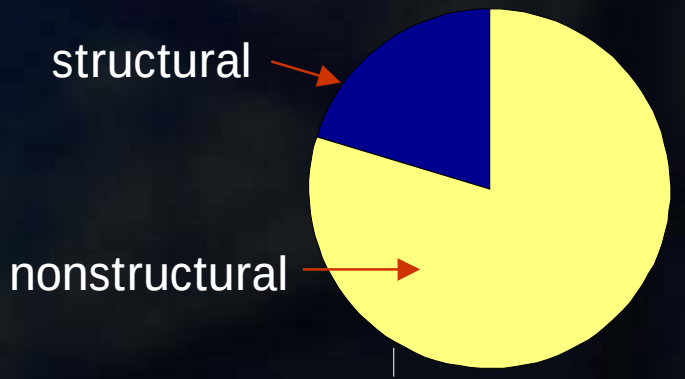
(a) Expected cost for M7 scenario

$8.0M

(b) 90% confidence cost does not exceed threshold for 475-yr return period hazard level

$240,000

(c) Mean cumulative annual total cost of damage



(d) Contributions to total cost for scenario

Performance-Based Earthquake Engineering

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A great tool to asses the relative seismic performance of different structural systems and aid in the selection of the structural system for a particular project

Much work remains to be done on the non-structural and content fragility functions

Thank You

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Designers should consider floor accelerations
when they next select or recommend
a Structural System
until

PEER and ATC 58 have completed the tools to perform PBEE

Great Promise of PBEE
in Transforming Decision Making Process of SE's