Are we designing for the correct level of seismic hazard across the Wasatch fault?

Mohsen Zaker Esteghamati, Ph.D.

Marv Halling, Ph.D., S.E.

Brady R. Cox, Ph.D., P.E.

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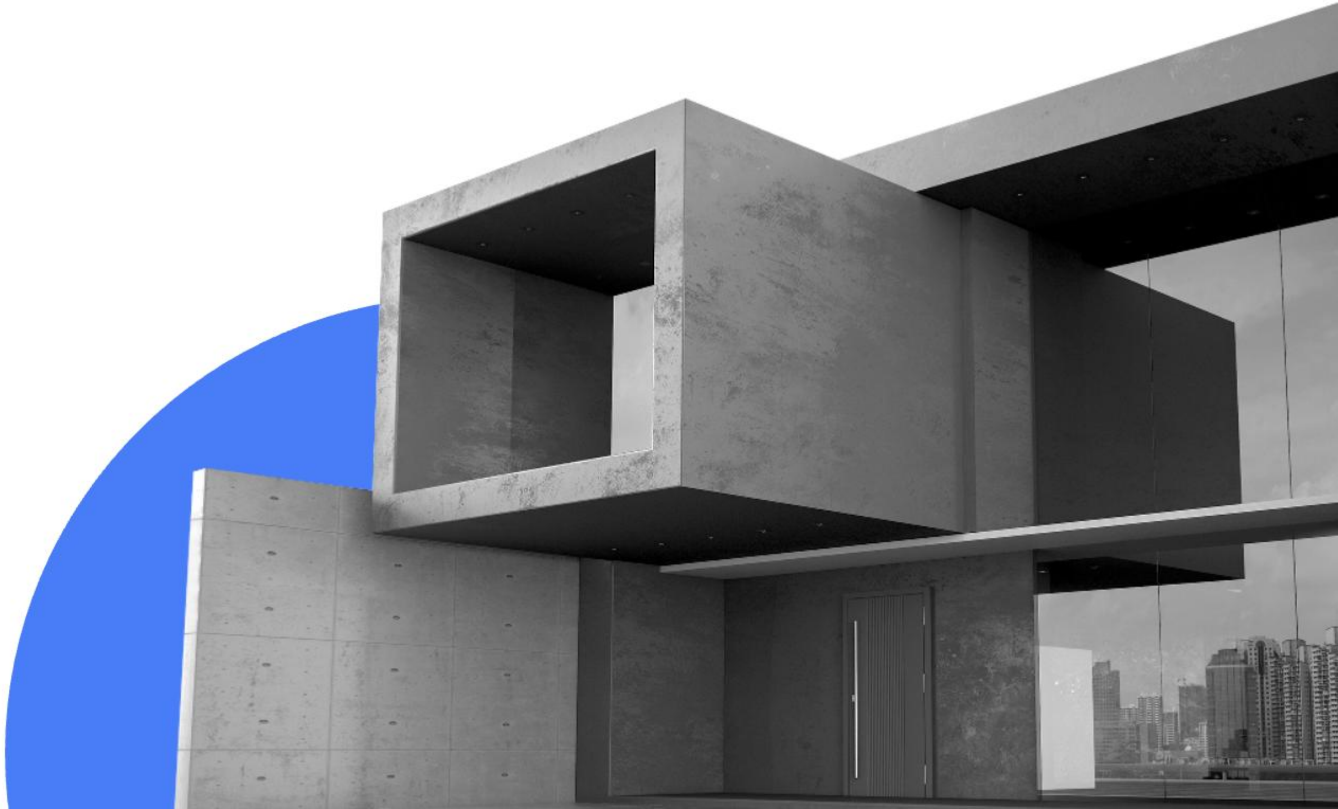


Utah Earthquake Engineering Center (UEEC)

UEEC Leadership Team

Brady Cox
Center Director
Geotechnical program lead

Expertise: geotechnical earthquake engineering, ground response analyses, soil liquefaction, dynamic site characterization
Email: brady.cox@usu.edu
Webpage: Dr. Cox's profile

Marv Halling
Structural program lead

Expertise: Earthquake engineering, structural health monitoring, structural dynamics
Email: marv.halling@usu.edu
Webpage: Dr. Halling's profile

Mohsen Zaker Esteghamati
Earthquake Resilience lead

Expertise: Performance-based engineering; Disaster resiliency; Risk-based design and assessment of structures; Machine learning and data-driven modeling
Email: mohsen.zaker@usu.edu
Webpage: Dr. Zaker

UEEC Affiliate Faculty

Alexis Ault
Geoscience
Associate professor

Expertise: earthquake geology, thermochronology
Email: alexis.ault@usu.edu
Webpage: Dr. Ault's profile

Srishti Banerji
Assistant Professor
Structural Engineering

Expertise: Property characterization of high-performance and sustainable construction materials, Full-scale testing and numerical simulations for evaluating structural components; Non-destructive testing
Email: srishti.banerji@usu.edu
Webpage: Dr. Banerji's profile

Kelian Dascher-Cousineau
Geoscience
Assistant Professor

Expertise: Earthquake source physics and forecasting, fault mechanics and tectonic geomorphology.
Email: kelian.dascher-cousineau@usu.edu
Webpage: Dr. Dascher-Cousineau's profile

Alba Rodriguez Padilla
Geoscience
Assistant Professor

Expertise: Earthquake and fault mechanics, remote sensing
Email: alba.rodriguez@usu.edu
Webpage: Dr. Rodriguez Padilla's profile

Srisharan Shreedharan
Geoscience

Expertise: Rock Deformation, Fault Friction, Earthquake Mechanics, Granular Physics
Email: srisharan.shreedharan@usu.edu
Webpage: Dr. Shreedharan's profile

James Bay
Associate Professor
Geotechnical engineering

Expertise: Engineering Geophysics, Soil Dynamics, Soil Mechanics, and MSE Retaining Structures
Email: jim.bay@usu.edu
Webpage: Dr. Bay's profile

Brennan Bean
Assistant Professor
Statistics

Expertise: Spatial Statistics, Computational Statistics, Statistical Visualization
Email: brennan.bean@usu.edu
Webpage: Dr. Bean's profile

Stacia Ryder
Sociology
Assistant professor

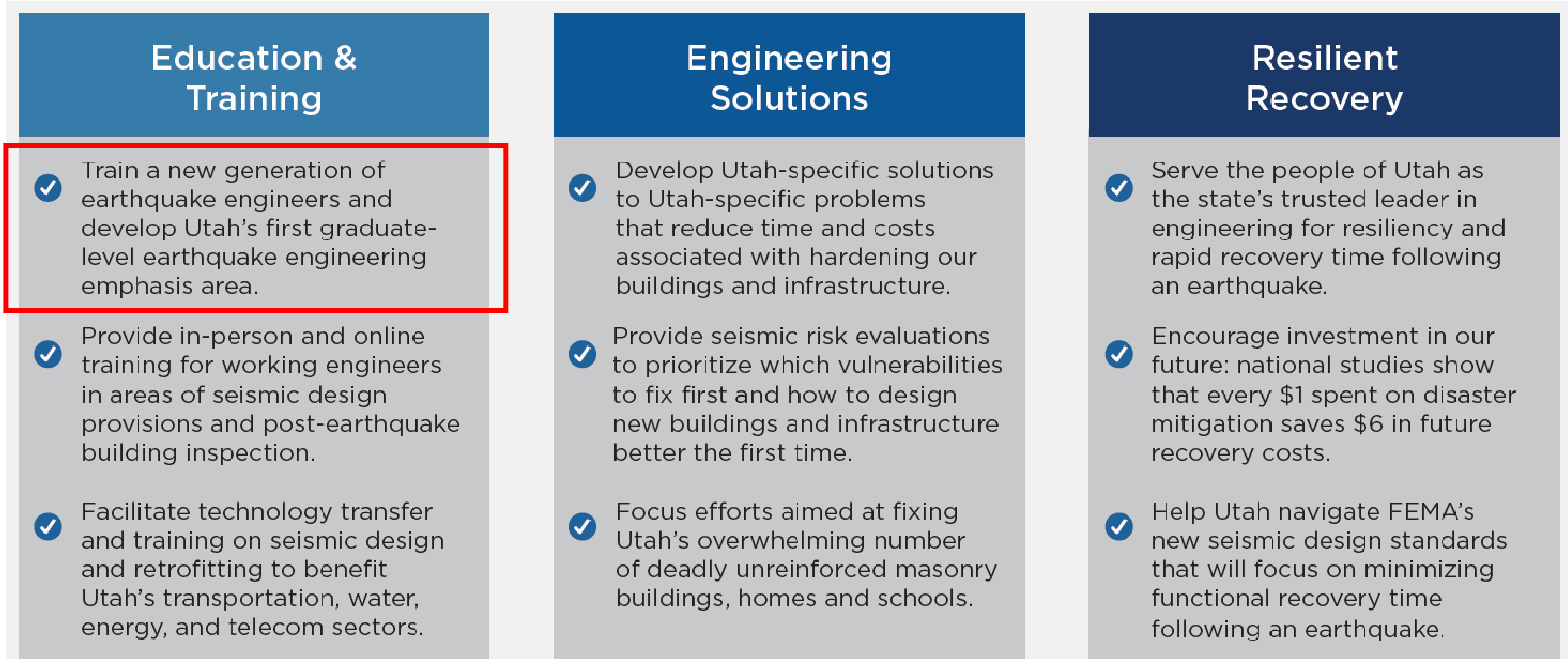
Expertise: disaster vulnerability and justice, climate adaptation planning, and community and stakeholder engagement
Email: stacia.ryder@usu.edu
Webpage: Dr. Ryder's profile

Soheil Shafaei
Structural Engineering
Assistant Professor

Expertise: Large-Scale Experiments in Earthquake Engineering, Advanced Finite Element Modeling (3D, 2D, Fiber-Based Modeling), Seismic Design of Steel and Steel-Concrete Composite Lateral Load-Resisting

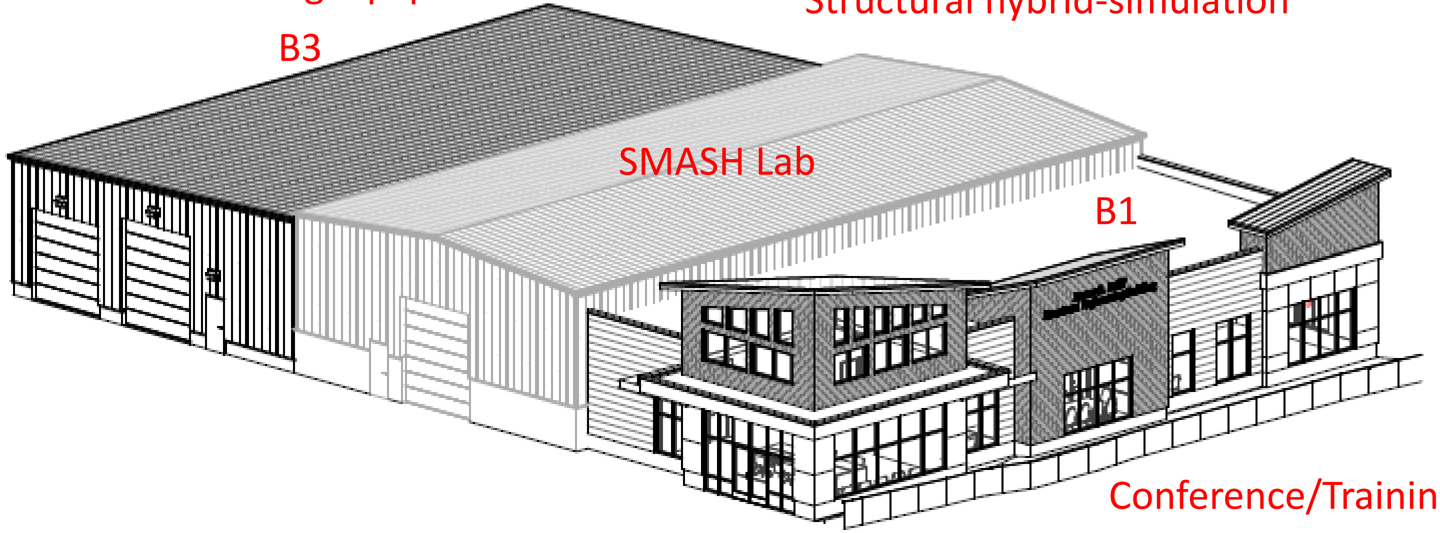
UEEC Focus Areas

Promoting resiliency and rapid recovery following a large earthquake by focusing on:



Education & Training	Engineering Solutions	Resilient Recovery
✓ Train a new generation of earthquake engineers and develop Utah's first graduate-level earthquake engineering emphasis area.	✓ Develop Utah-specific solutions to Utah-specific problems that reduce time and costs associated with hardening our buildings and infrastructure.	✓ Serve the people of Utah as the state's trusted leader in engineering for resiliency and rapid recovery time following an earthquake.
✓ Provide in-person and online training for working engineers in areas of seismic design provisions and post-earthquake building inspection.	✓ Provide seismic risk evaluations to prioritize which vulnerabilities to fix first and how to design new buildings and infrastructure better the first time.	✓ Encourage investment in our future: national studies show that every $1 spent on disaster mitigation saves $6 in future recovery costs.
✓ Facilitate technology transfer and training on seismic design and retrofitting to benefit Utah's transportation, water, energy, and telecom sectors.	✓ Focus efforts aimed at fixing Utah's overwhelming number of deadly unreinforced masonry buildings, homes and schools.	✓ Help Utah navigate FEMA's new seismic design standards that will focus on minimizing functional recovery time following an earthquake.

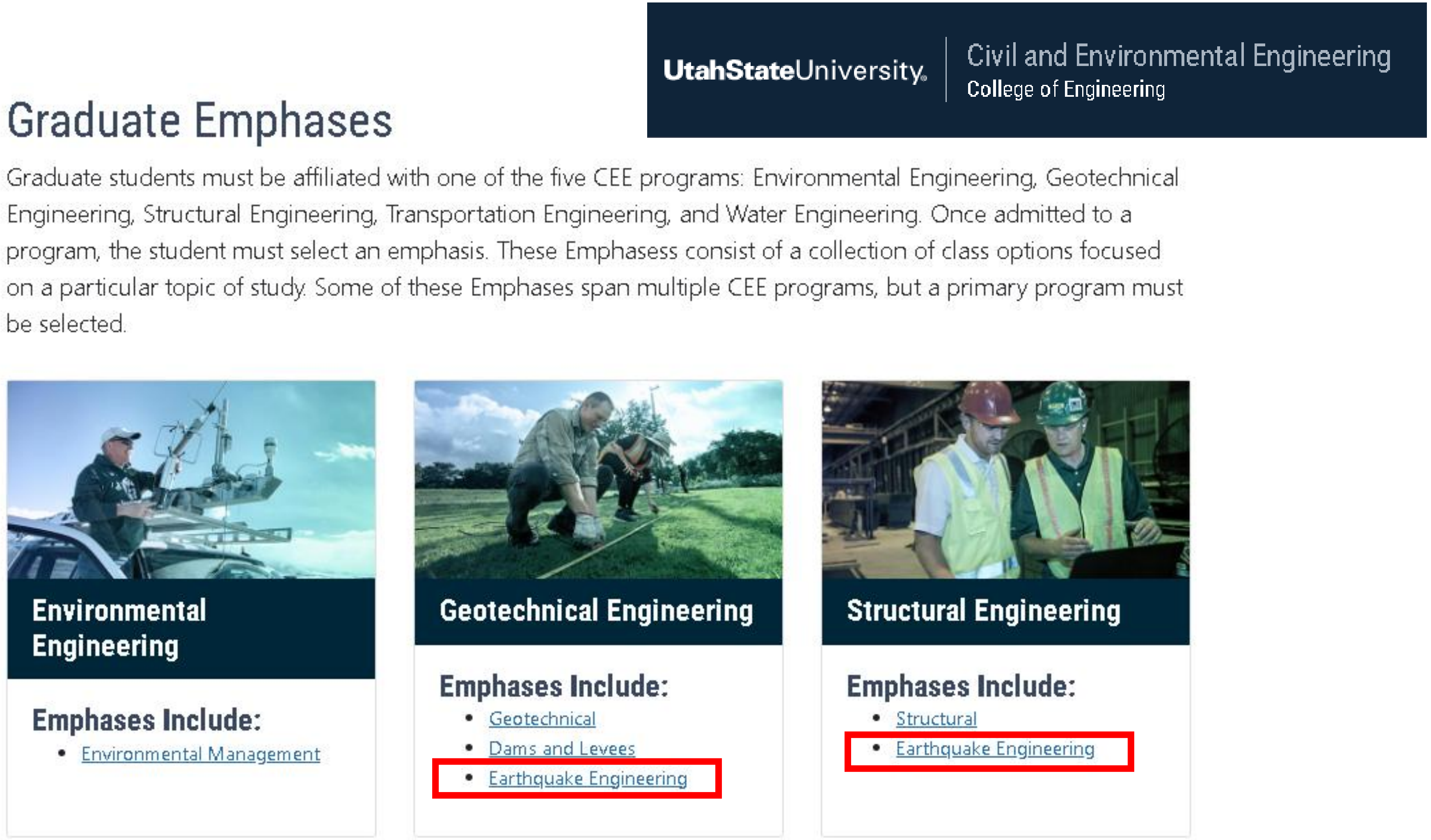
Plans for New UEEC Buildings and Labs



- B1: New James D. Ballif Structural Engineering Building ($1.25M gift)
- B3: New UEEC laboratory
- Approximately triple the existing lab/office space
- Approximately $3.5M investment

Earthquake Engineering Emphasis

We have started the first earthquake engineering graduate student emphasis area in Utah



UtahStateUniversity.
Civil and Environmental Engineering
College of Engineering

Graduate Emphases

Graduate students must be affiliated with one of the five CEE programs: Environmental Engineering, Geotechnical Engineering, Structural Engineering, Transportation Engineering, and Water Engineering. Once admitted to a program, the student must select an emphasis. These Emphasess consist of a collection of class options focused on a particular topic of study. Some of these Emphases span multiple CEE programs, but a primary program must be selected.

Environmental Engineering

Emphases Include:

- Environmental Management

Geotechnical Engineering

Emphases Include:

- Geotechnical
- Dams and Levees
- Earthquake Engineering

Structural Engineering

Emphases Include:

- Structural
- Earthquake Engineering

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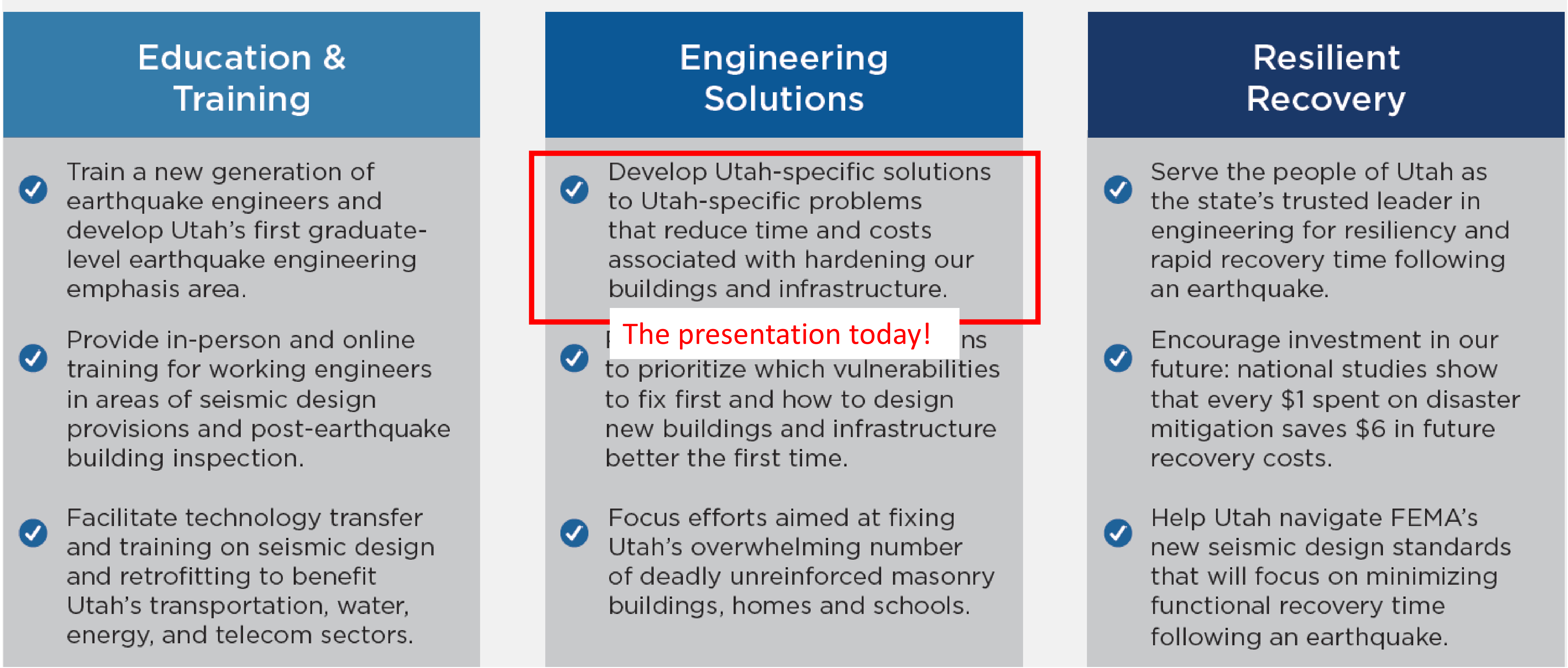

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The presentation today!

BACKGROUND

METHODOLOGY

RESULTS

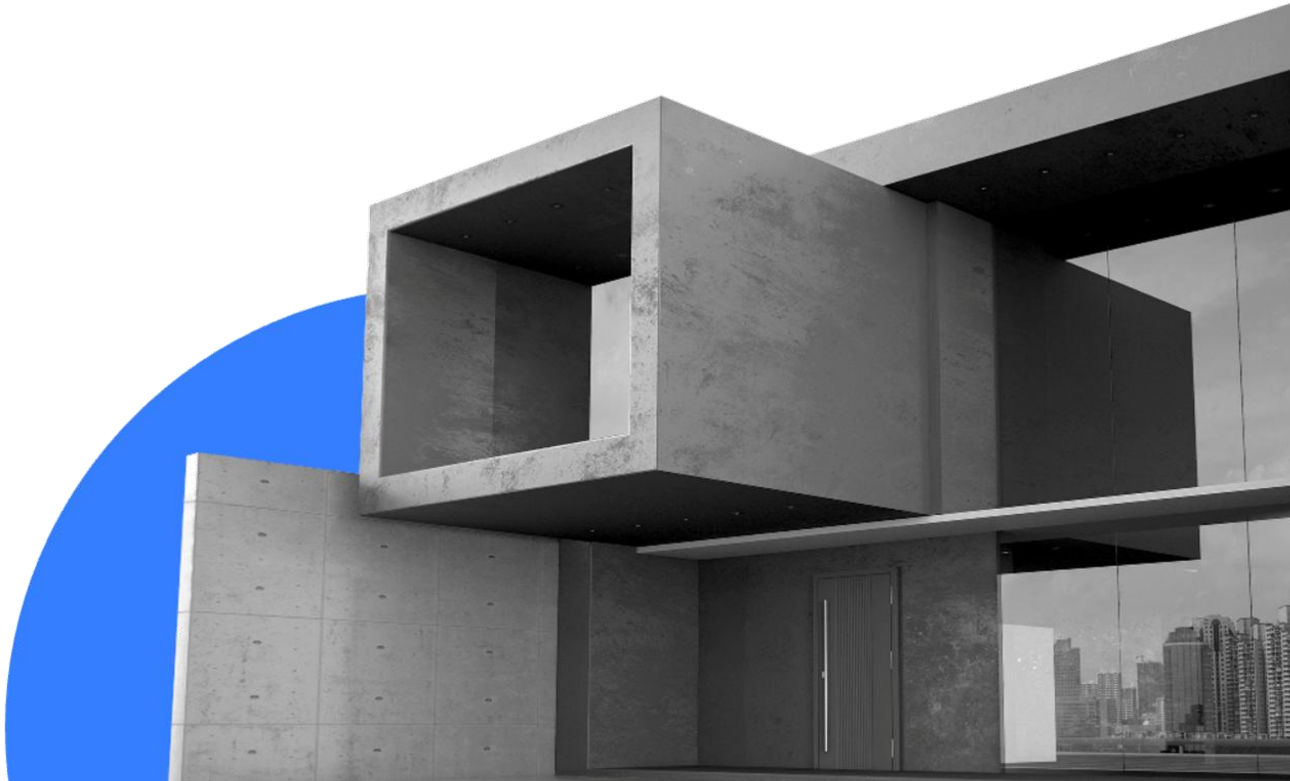
CONCLUSION

Background and Motivation

Utah’s Seismic Hazard

Seismic Hazard Analysis

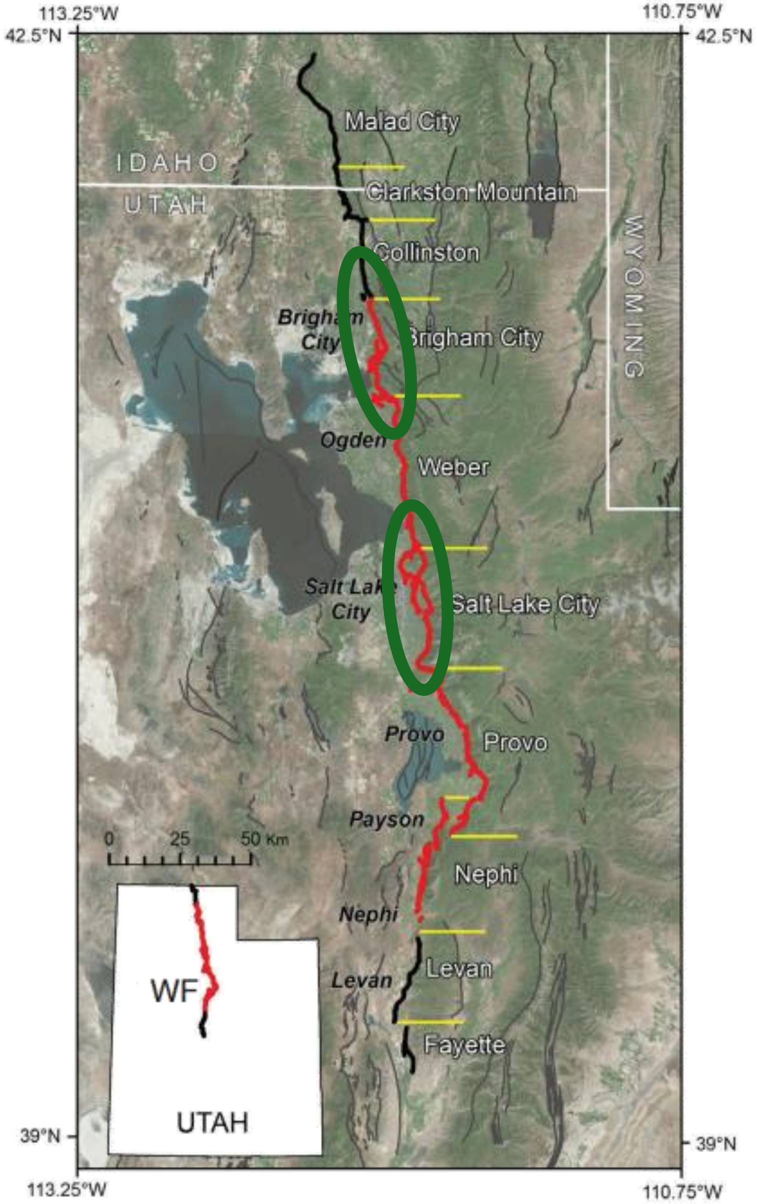
Research Objectives



Utah seismic hazard

Wasatch Fault

- Normal fault type
- Central segments produce magnitude (M_w) 7.0 earthquakes
- Probability of a M_w 6.75 or higher earthquake from 2014-2063 (Wong et al. 2016) :
    - **18%** along the Wasatch Fault
    - **6%** for Brigham City and Salt Lake City Segments
- Estimated economic loss: $33 billion (Pankow et al. 2015)
    - 84,400 households are estimated to be displaced (Pankow et al. 2015)
    - Magna 2020 M_w 5.7 cost upwards of $100 million in building-related damages (Utah Geological Survey 2022)



Wasatch Fault (Utah Geological Survey, 2022)

Seismic Hazard Analysis (SHA)

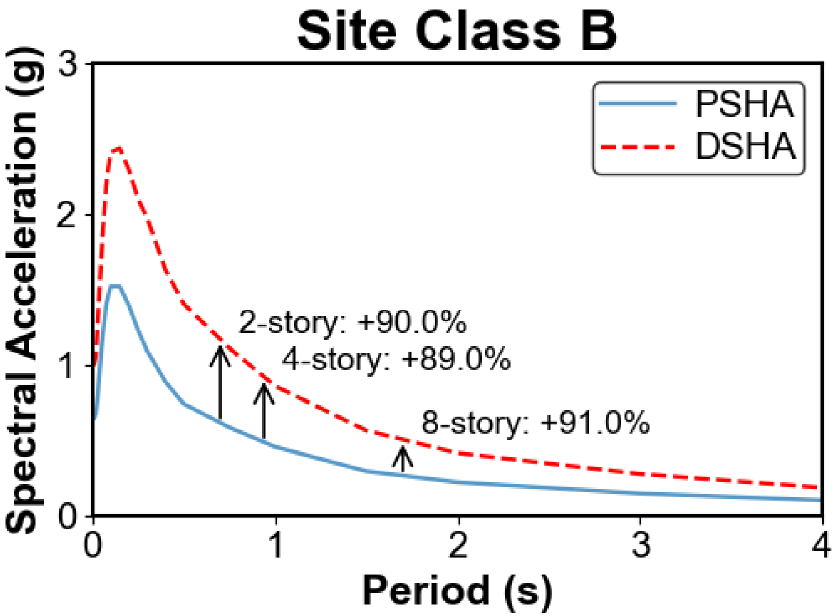
Probabilistic SHA (PSHA)

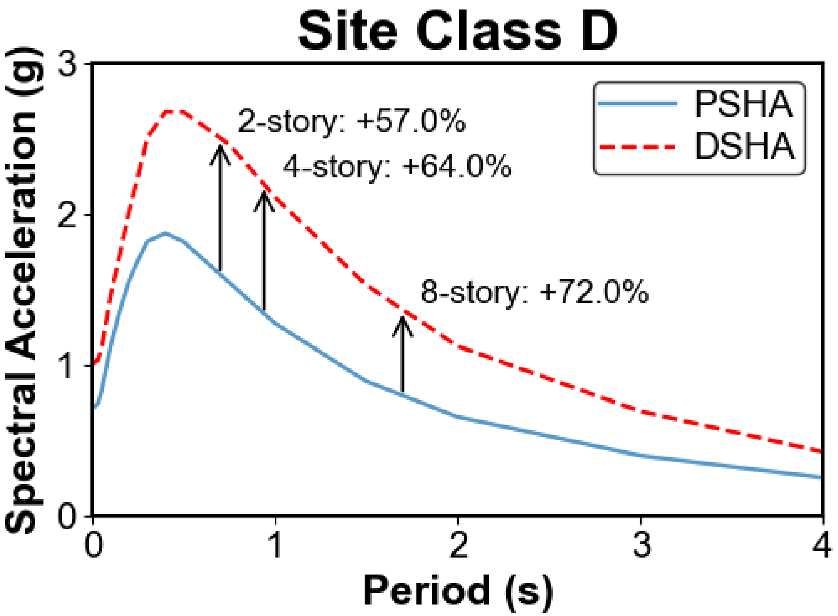
All possible earthquake scenarios, **weighted by likelihood** to calculate the probability of exceeding a given GM level over a specified time frame

Deterministic SHA (DSHA)

A single earthquake scenario determines the GM that could be generated without considering the probability of its occurrence within a specified time frame

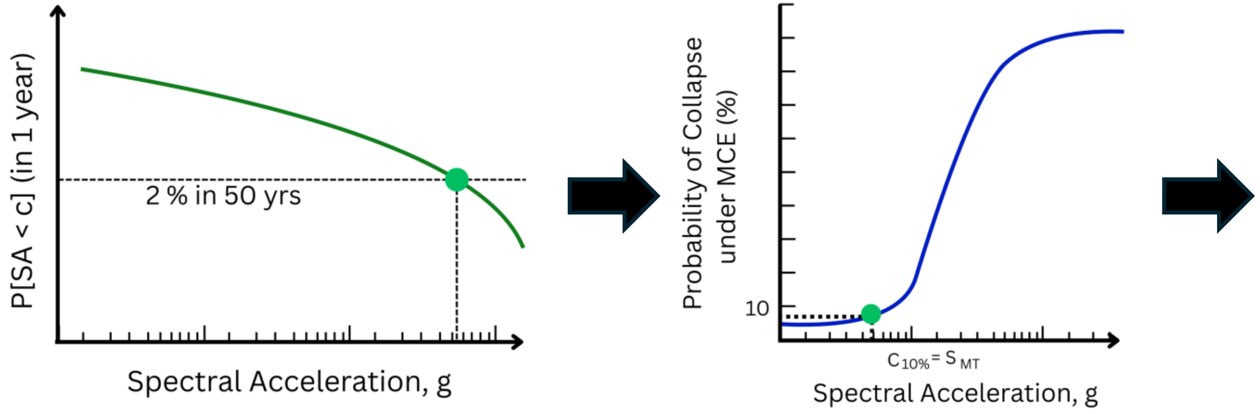
Modern building codes (i.e., ASCE 7) design is based on the **lower** of the two analyses





How is PSHA used in ASCE 7-22?

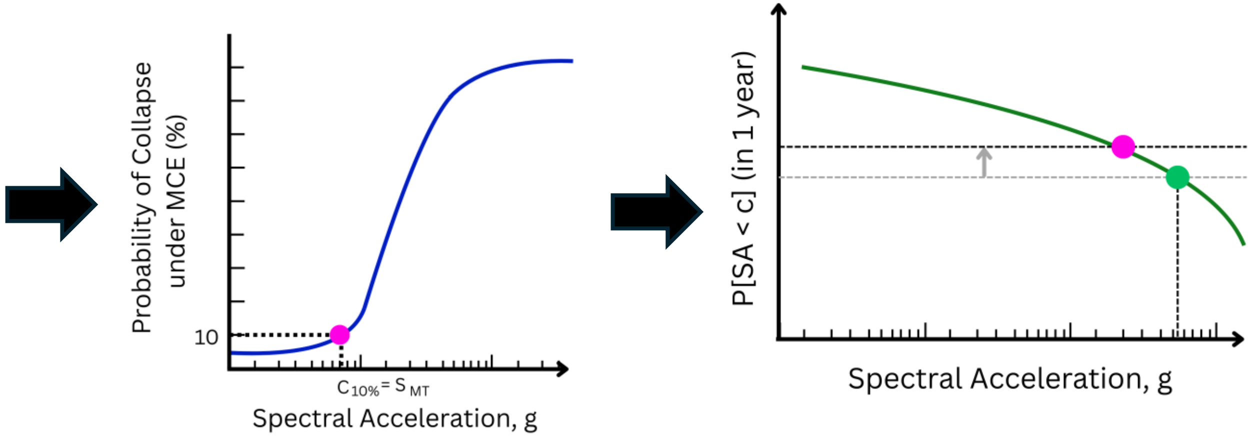
Typical PSHA



P[Collapse in 50 yrs]

Risk-Targeted PSHA

P[Collapse in 50 yrs] = 1%

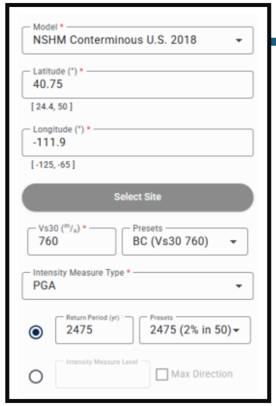


How can DSHA be used in ASCE 7-22?

- Determine the DSHA GM for each period based on the risk-targeted PSHA disaggregated EQ scenarios that contribute >10% to the hazard

Repeat for all periods in Multi-pt spectrum

Identify Site and Period



Model * NSHM Conterminous U.S. 2018

Latitude (°) * 40.75

[24.4, 50]

Longitude (°) * -111.9

[-125, -65]

Vs30 (m/s) * 760

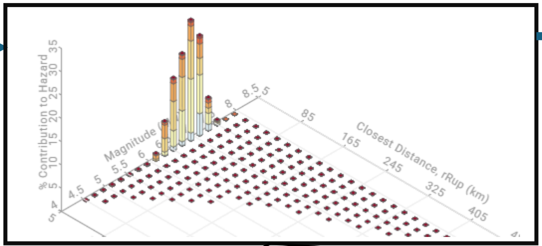
Presets BC (Vs30 760)

Intensity Measure Type * PGA

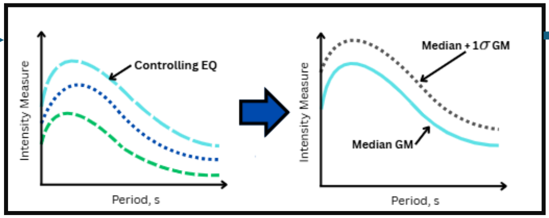
● Return Period (yr) 2475 Presets 2475 (2% in 50)

○ Intensity Measure Level ☐ Max Direction

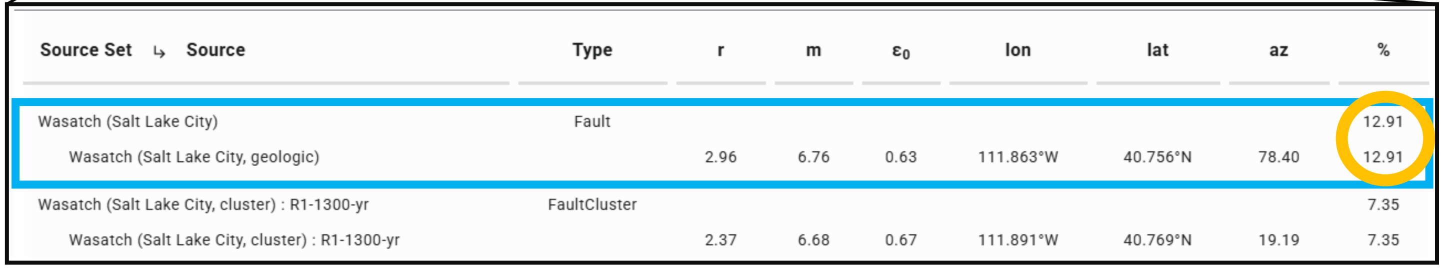
Disaggregate Contributions



Conduct DSHA



Set largest acceleration from the scenario EQs as the Sa at that period



Source Set ↳ Source	Type	r	m	ε0	lon	lat	az	%
Wasatch (Salt Lake City)	Fault							12.91
Wasatch (Salt Lake City, geologic)		2.96	6.76	0.63	111.863°W	40.756°N	78.40	12.91
Wasatch (Salt Lake City, cluster) : R1-1300-yr	FaultCluster							7.35
Wasatch (Salt Lake City, cluster) : R1-1300-yr		2.37	6.68	0.67	111.891°W	40.769°N	19.19	7.35

Some considerations on ASCE 7-22 DSHA

- Comprised of 22 separate ‘worst case’ scenarios
- Based on the risk-targeted PSHA analysis
  - All-time biases are being brought into DSHA
- Accounts for deep basin effects, but overlooks unique aspects of Utah’s tectonic environment
  - Hanging wall effect, normal fault type, etc.
- Limited DSHA data due to the PSHA-based calculations **not exceeding** the threshold required to trigger the DSHA computation based on current code

Determining DSHA level forces:

- ✓ Process based on FEMA P-2078 (Tong et al. 2020)
- ✓ Obtain **84th percentile** level forces from equally weighted four ground motion models (GMMs) :
  - ✓ **(1)** Abrahamson, Silva, and Kamai, 2014 (**ASK14**), **(2)** Boore, Stewart, Seyhan, and Atkinson, 2014 (**BSAA14**), (**3**) Campbell and Bozorgnia, 2014 (**CB14**), (**4**) Chiou and Youngs, 2014 (**CY14**)
- ✓ Apply the maximum direction factor to transform the geometric mean GM into the maximum direction GM (Tong et al. 2020, ASCE 2022)

DSHA GMM inputs

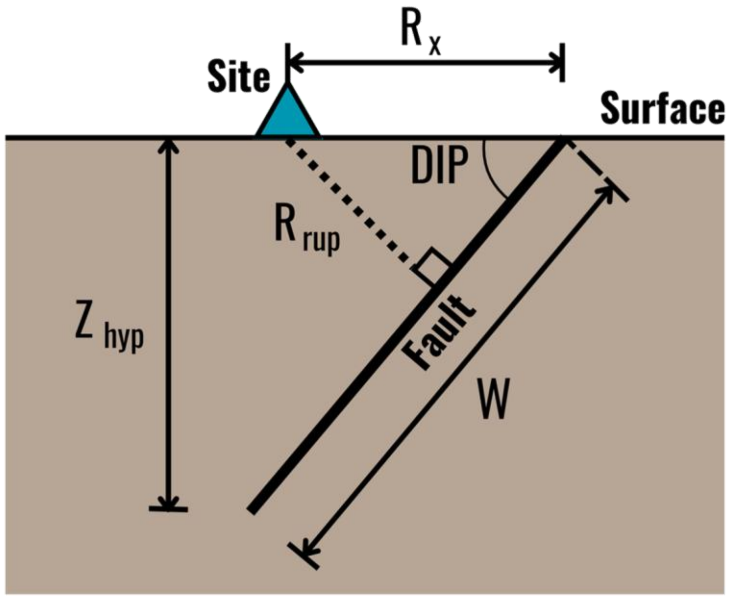
Working Group on Utah Earthquake Probabilities (WGUEP) Report (Wong et al. 2016) :

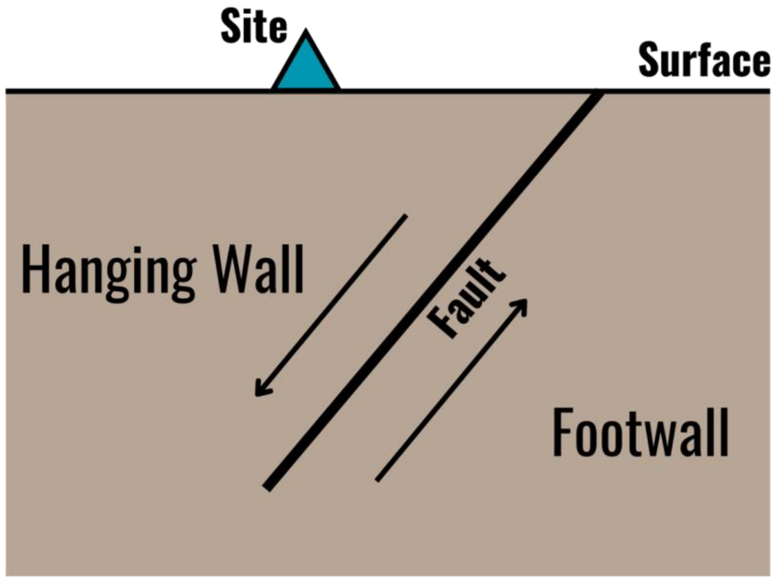
M_w : 7.12 Dip Angle: 50° Depth to hypocenter (Z_{hyp}): 15 km

Geometric Inputs:

R_{jb} = 0 km W = 19.5 km Depth to rupture Z_{tor}0 = km
R_x= 3.1 km R_{rup} = 2.37 km

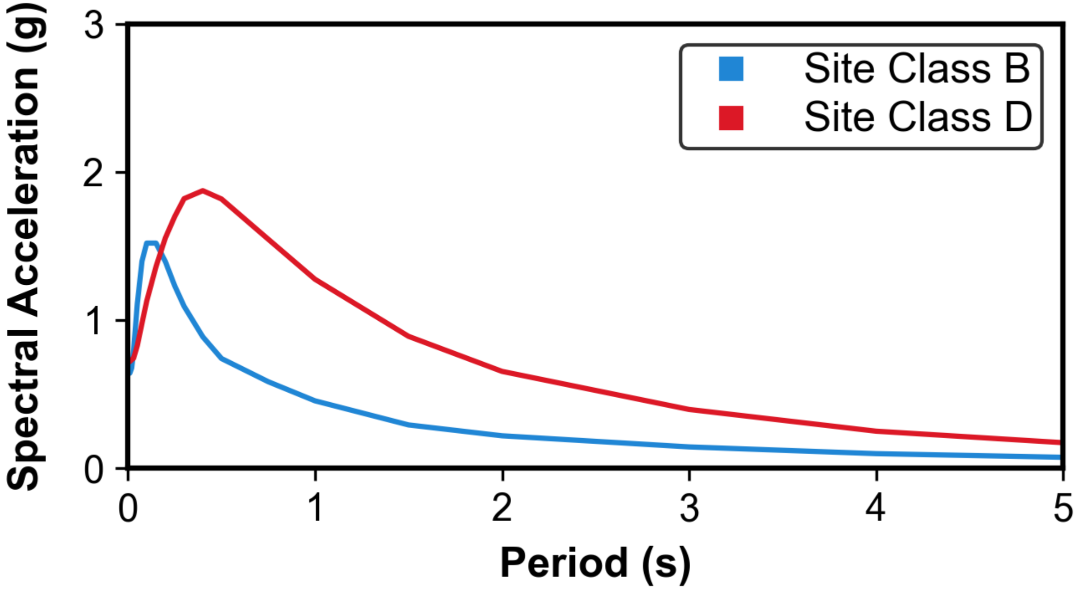
Basin Amplification: $Z_{1.0}$ = 0.436 km $Z_{2.5}$ = 2.71 km



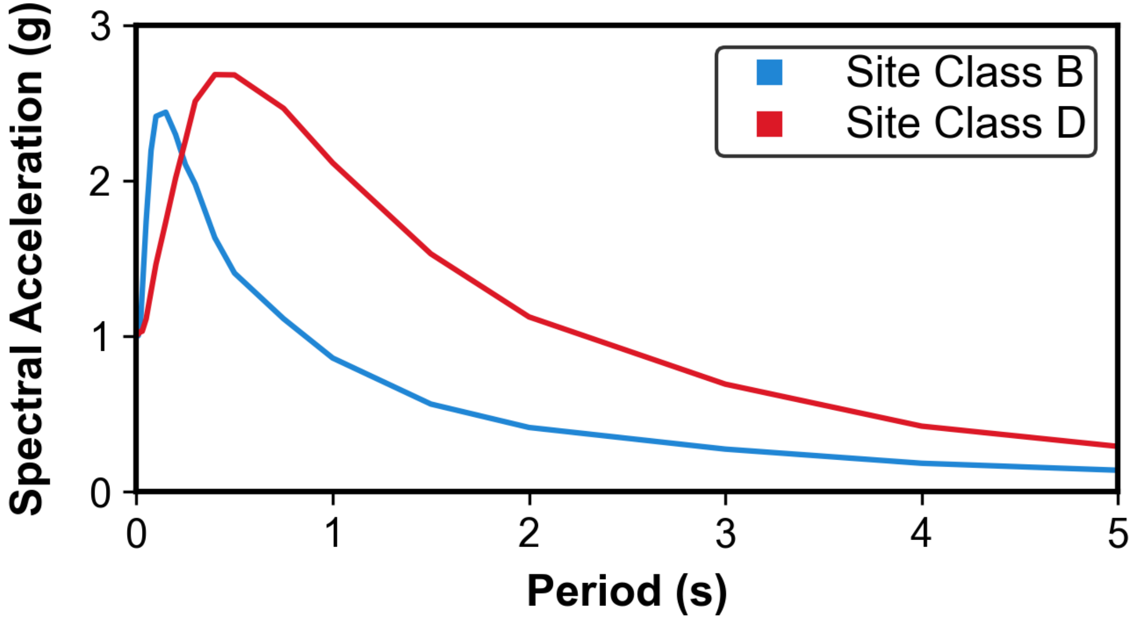


MCE response spectra

PSHA-based MCE spectra



DSHA-based MCE spectra

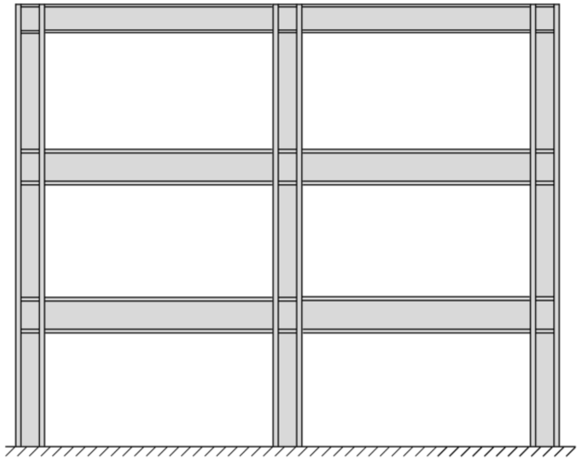


Objectives

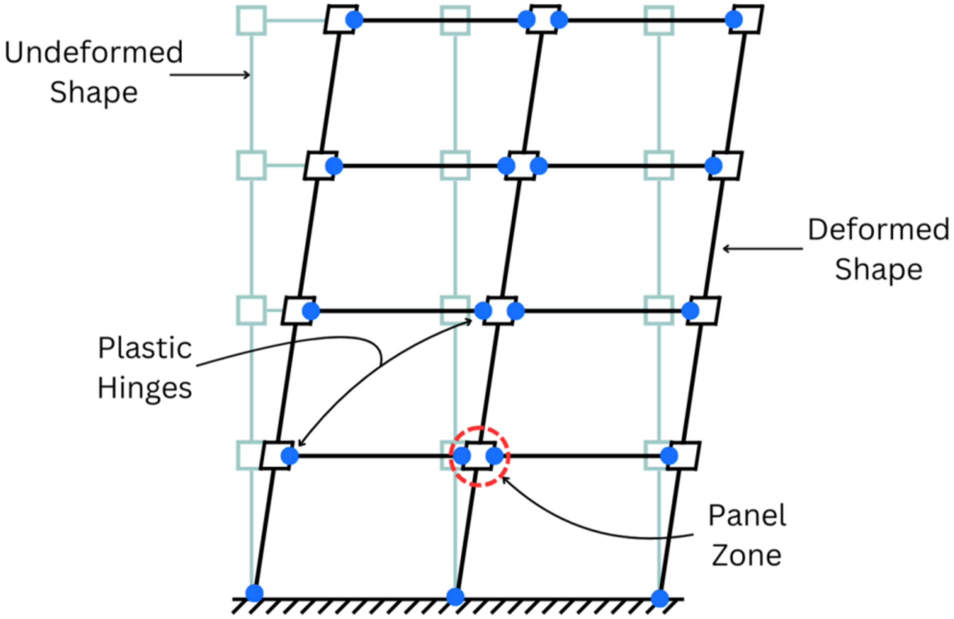
1. Determine if structures designed to current seismic levels meet the life safety objective of the code under more realistic seismic hazard representation
    1. 10% probability of collapse under MCE-scaled ground motion
2. Compare the collapse probability from PSHA- and DSHA-based MCE-scaled ground motions
3. Assess the results over a set of “archetype” buildings representative of the current design practices for a specific lateral-resisting system in the region

Steel special moment-resisting frames (SMRF)

- Architectural Benefits
- Ductile Lateral System
  - Designed to yield in beams rather than columns (Hamburger et al. 2009)
  - Strong-column weak-beam (Hamburger et al. 2009)

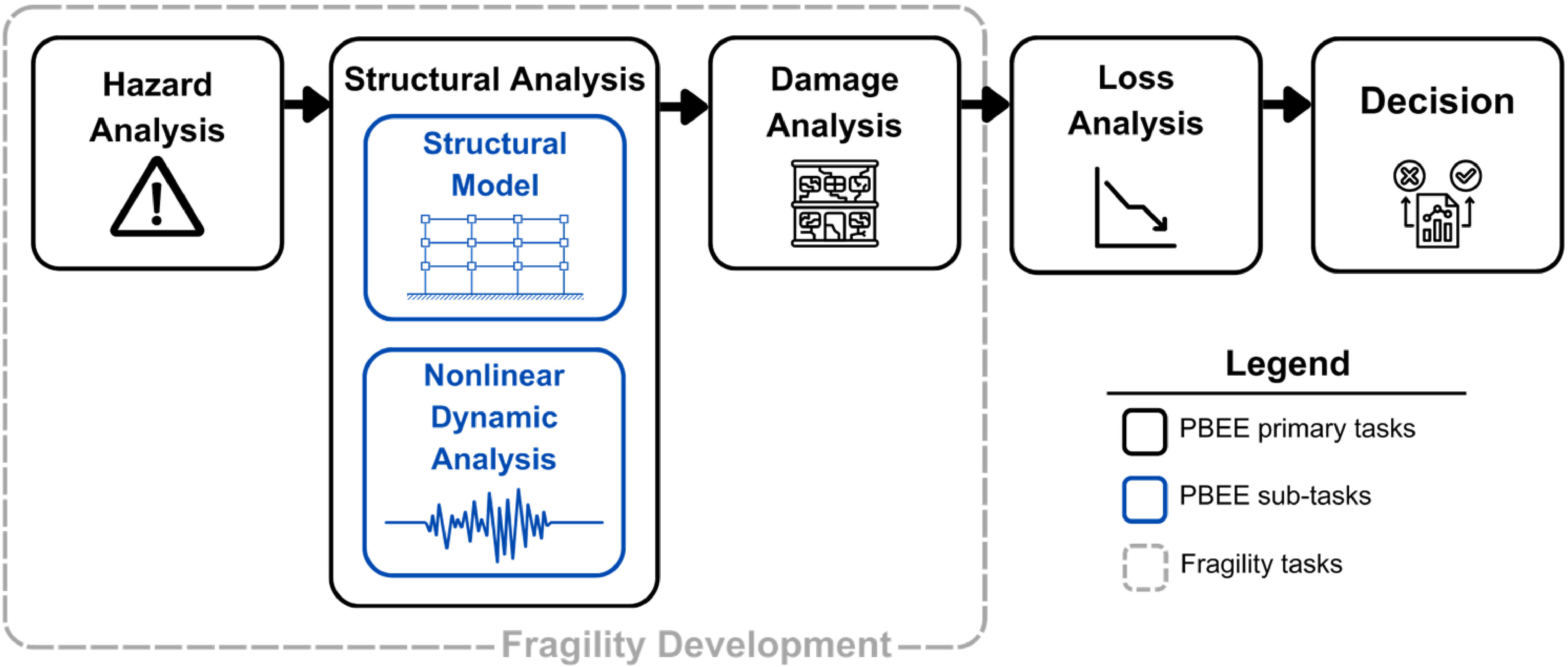


Typical SMRF Configuration



Idealized sidesway failure for strong-column weak-beam design

Performance based earthquake engineering (PBEE)



Hazard Analysis

Structural Analysis

Structural Model

Nonlinear Dynamic Analysis

Damage Analysis

Loss Analysis

Decision

Fragility Development

Legend

- ☐ PBEE primary tasks
- ☐ PBEE sub-tasks
- ⬚ Fragility tasks

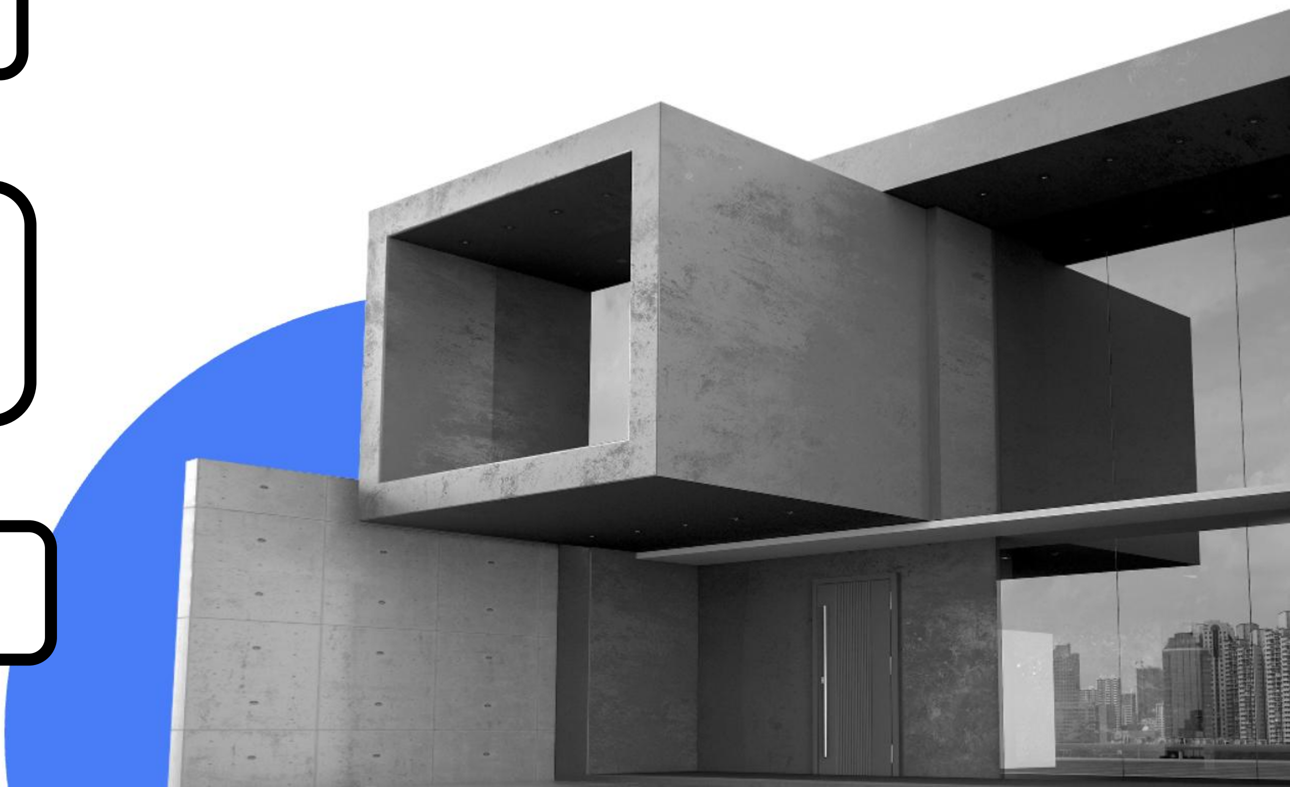
Methodology

Archetype Design

Nonlinear Finite Element Model

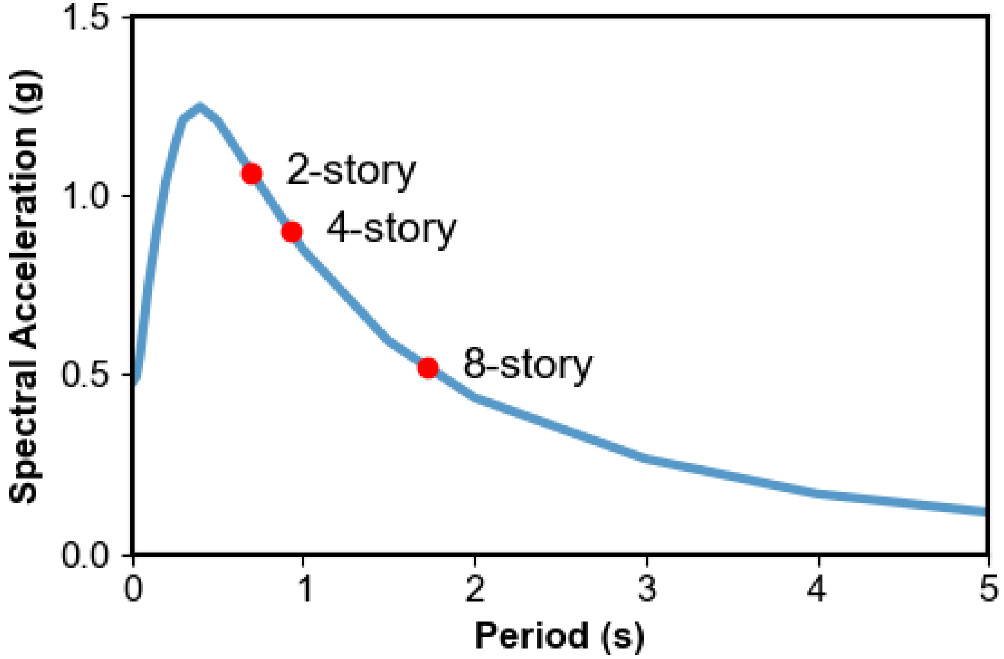
GM Selection/Scaling and nonlinear time history analysis

Collapse assessment



SMRF office building archetypes

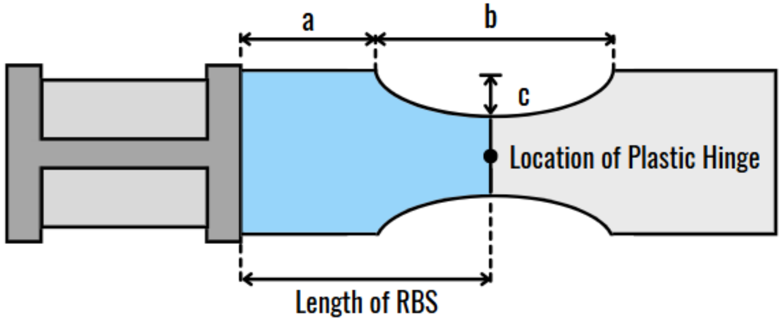
- Designed to represent Salt Lake City (40.75°, -111.9°) according to current codes:
  - ASCE 7-22, AISC 360, AISC 358, AISC 341
- Site Class D
- Typical Loads
  - Floor:
    - Dead = 61 psf
    - Live = 50 psf (Unreduced)
    - Partition = 15 psf
  - Roof:
    - Dead = 15 psf
    - Live = 20 psf
    - Snow = 35 psf



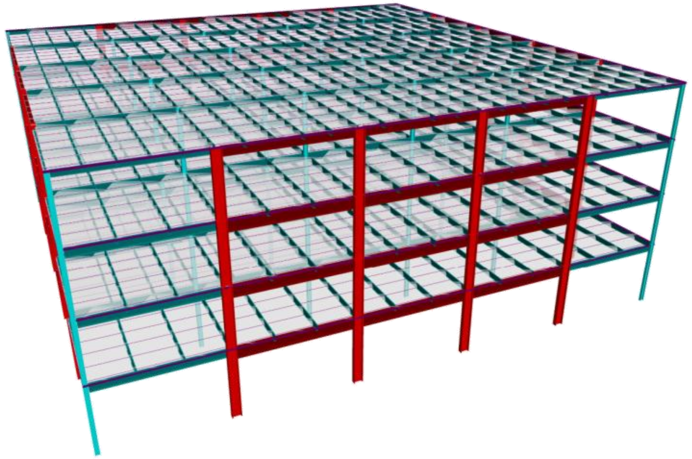
ASCE 7-22 Design Response Spectra

Design

- Uses prequalified Reduced Beam Section (RBS) connection (AISC, 2022c)
- Composite Floor and Beams
- Preferrable to increase the column weight by less than 100 lb./ ft than use a doubler plate
- Designed using the centerline model
  - No panel zone and rigid offset reduction in RAM SS
- Designed using RAM Structural System (Bentley, *RAM Structural System)*
- Equivalent Lateral Force Method



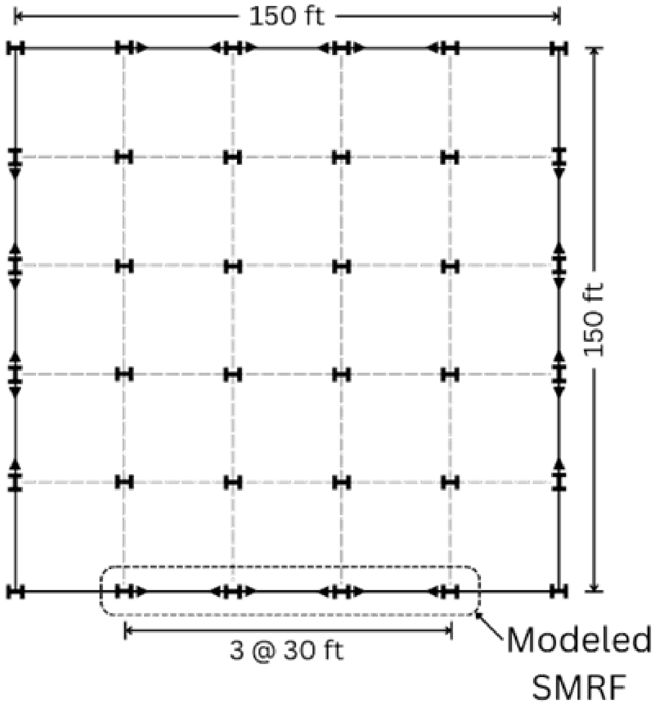
RBS Connection



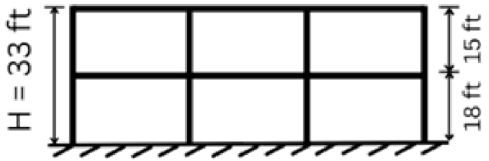
RAM Structural System Model

Archetype geometries

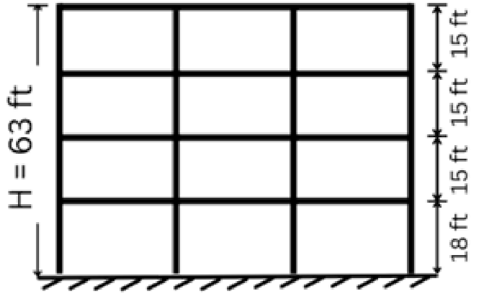
- SMRF behavior
- Archetype description



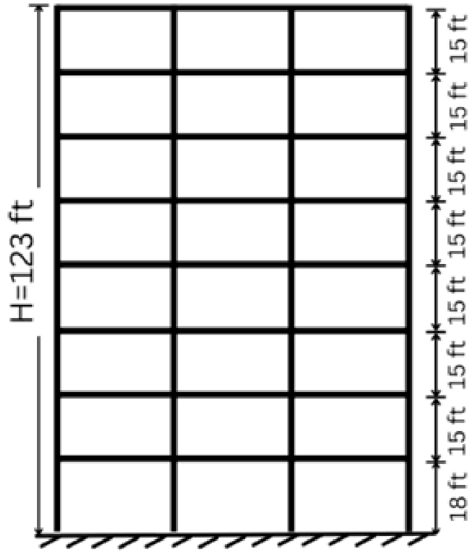
Floor Plan



2-story



4-story



8-story

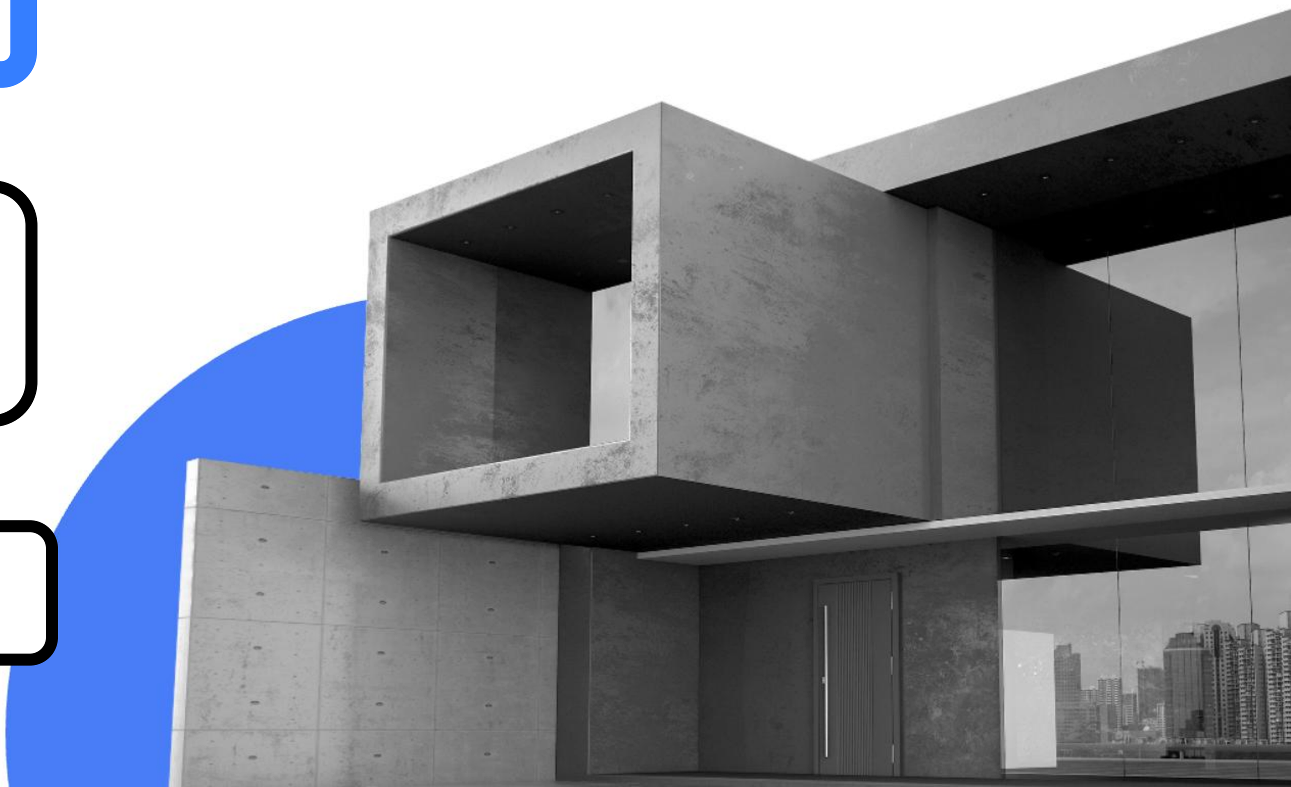
Methodology

Archetype Design

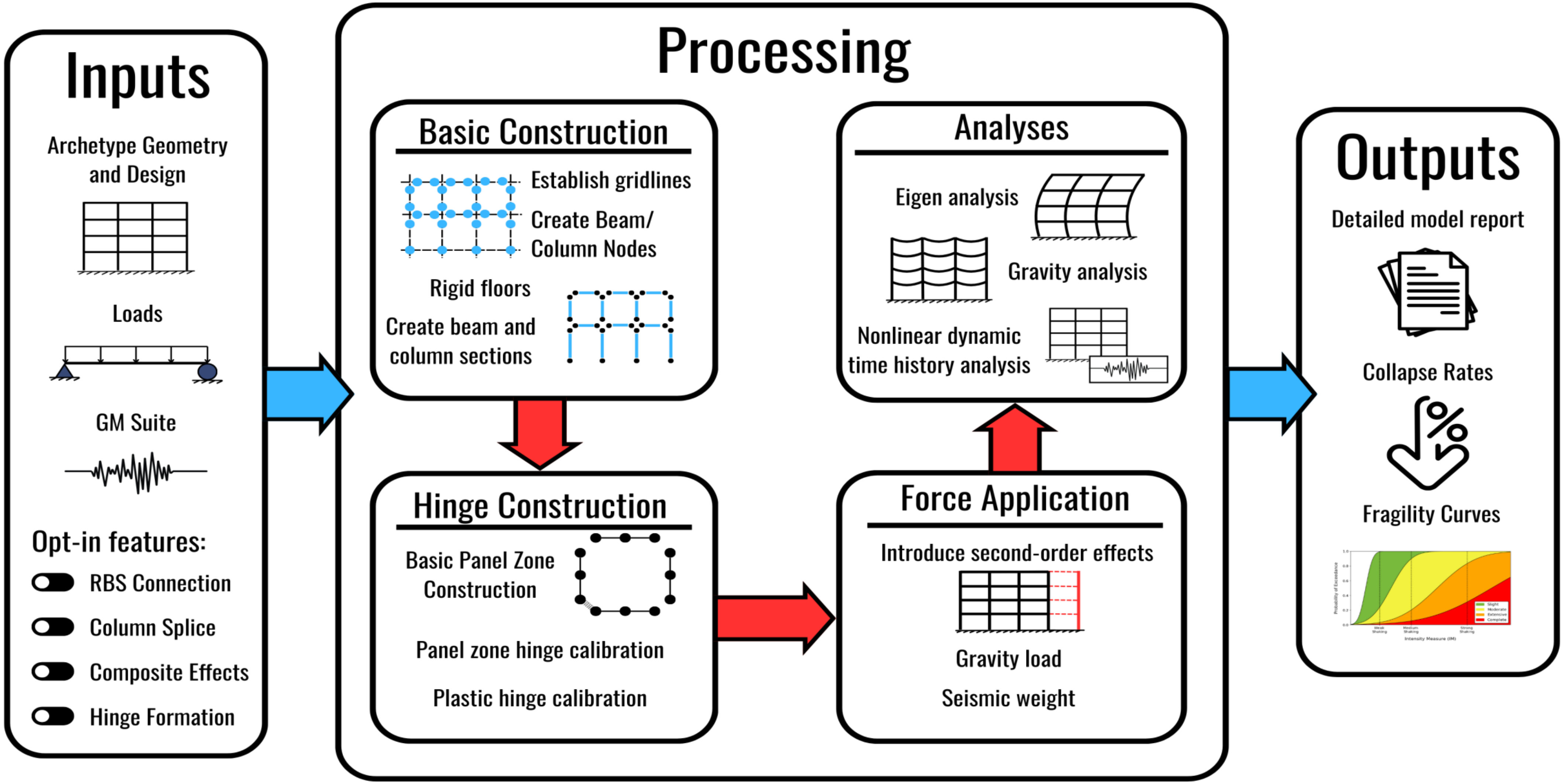
Nonlinear Finite Element Model

GM Selection/Scaling and nonlinear time history analysis

Collapse assessment



Modular finite element code



Inputs

Archetype Geometry and Design

Loads

GM Suite

Opt-in features:

- RBS Connection
- Column Splice
- Composite Effects
- Hinge Formation

Processing

Basic Construction

Establish gridlines

Create Beam/Column Nodes

Rigid floors

Create beam and column sections

Hinge Construction

Basic Panel Zone Construction

Panel zone hinge calibration

Plastic hinge calibration

Force Application

Introduce second-order effects

Gravity load

Seismic weight

Analyses

Eigen analysis

Gravity analysis

Nonlinear dynamic time history analysis

Outputs

Detailed model report

Collapse Rates

Fragility Curves

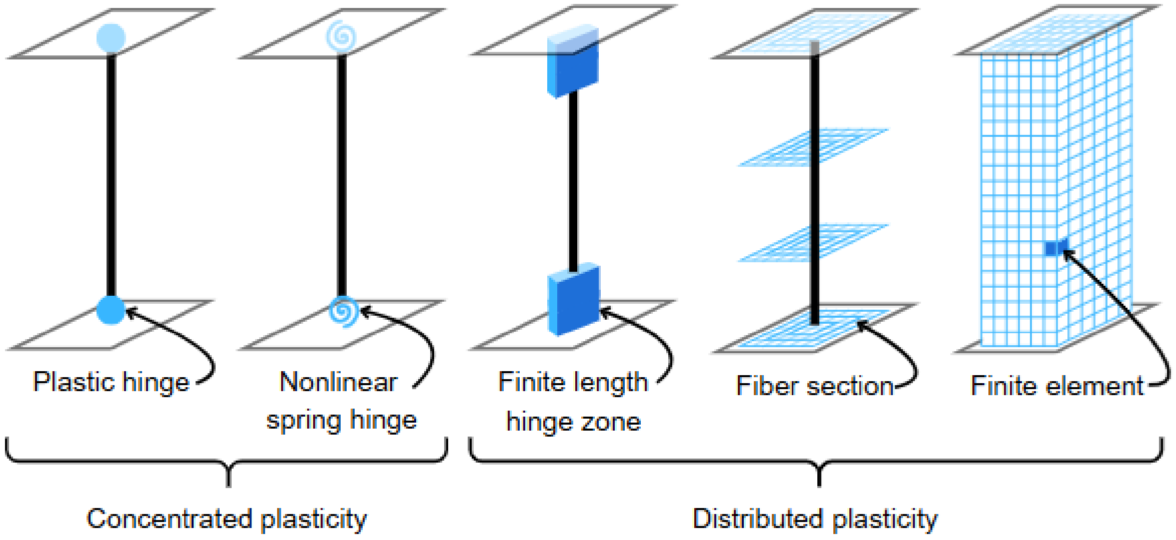
Plasticity modeling

Concentrated Plasticity

Captures nonlinear degradation through calibrated hinges (Deierlein et al. 2010)

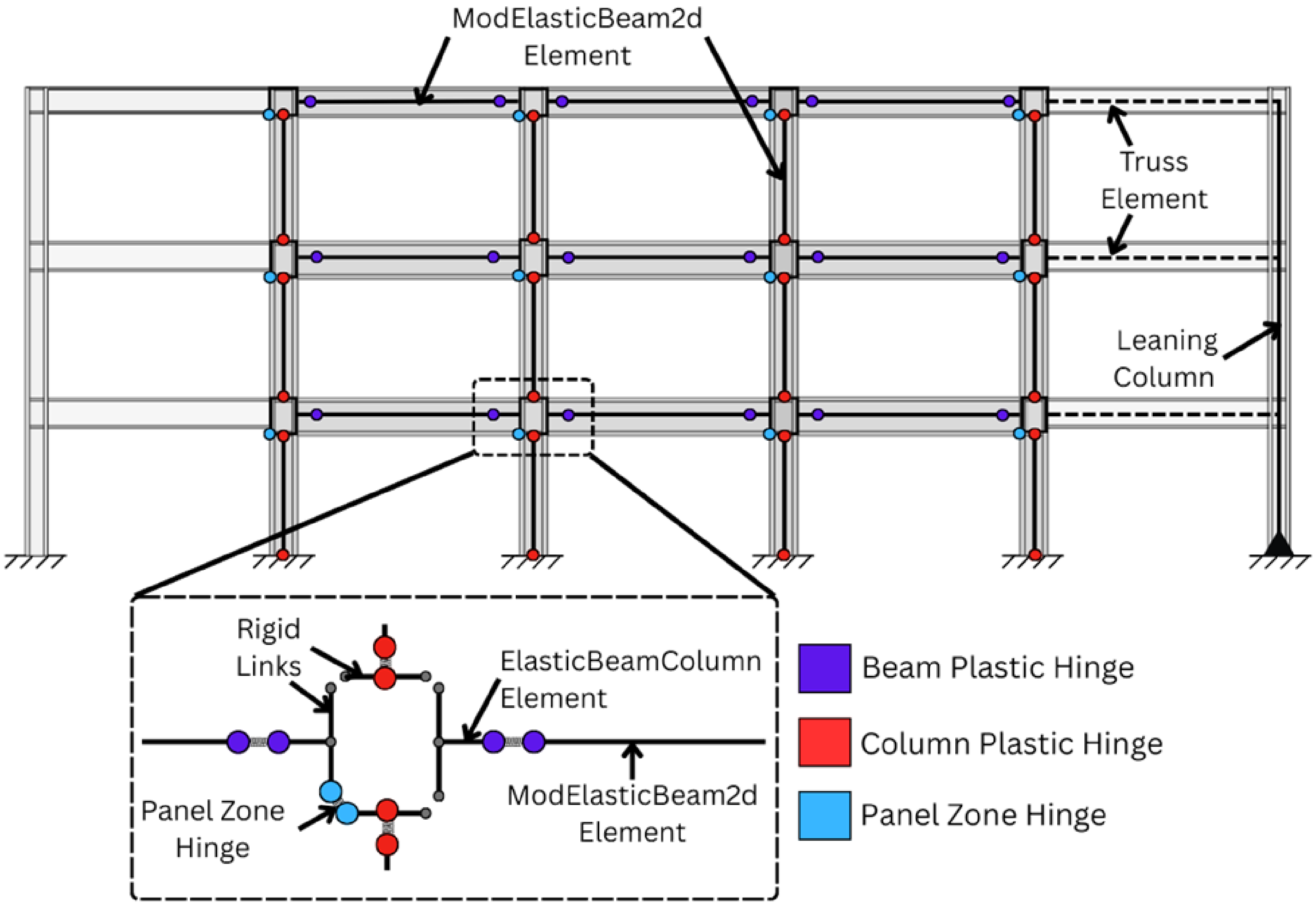
Distributed Plasticity

Captures variations in stress and strain along the member (Deierlein et al. 2010)

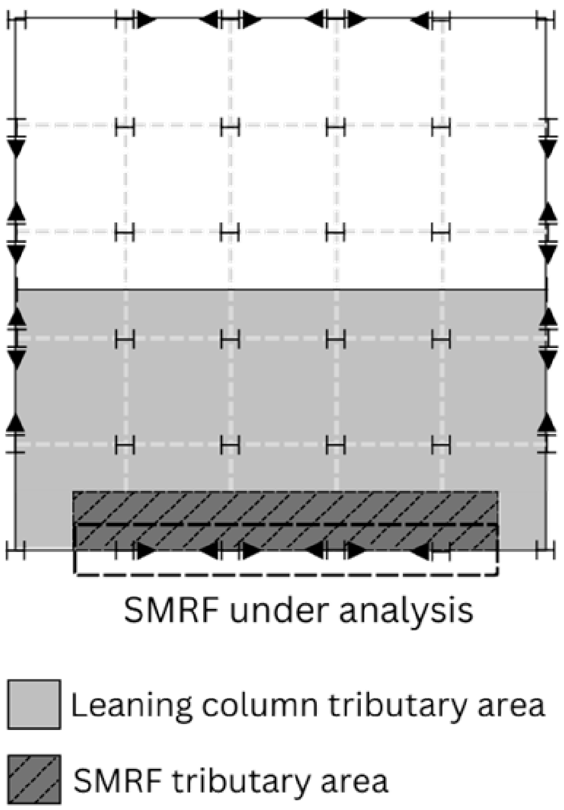


Idealized models for beam-column elements

Model configuration

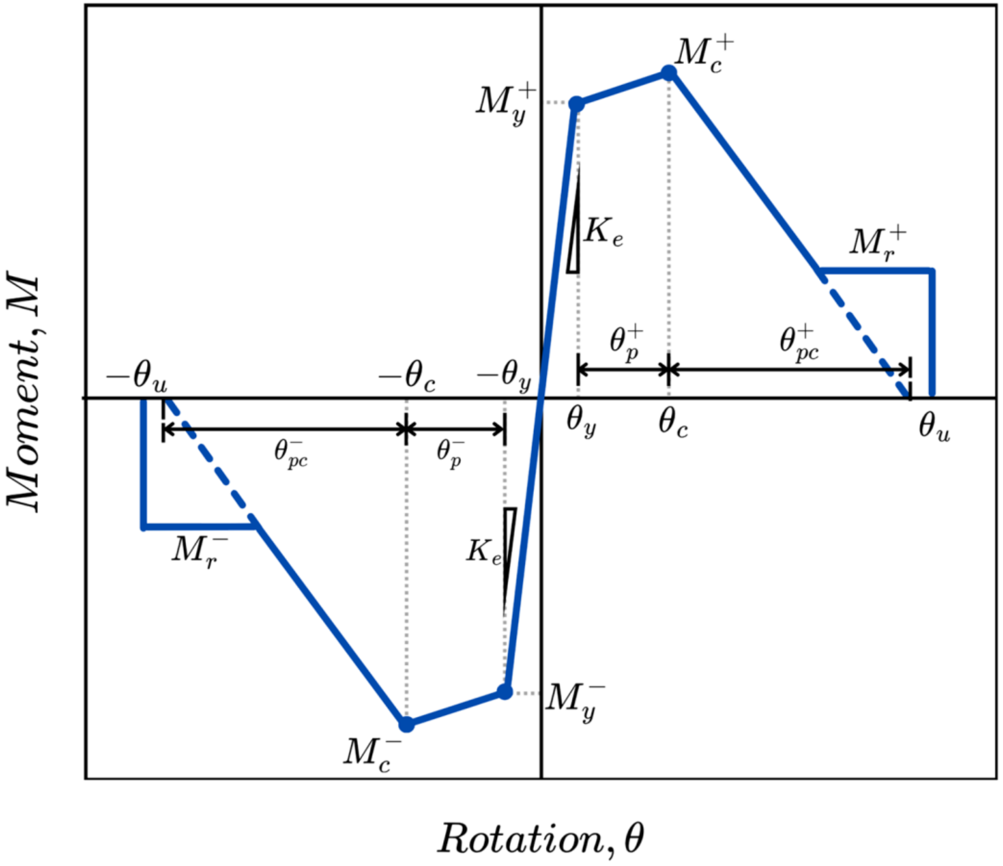


Modeled Elevation View



Floor Plan View

Modified Ibarra Krawinkler Model (IMK)



- A deterioration model to represent inelastic cyclic response
- Bounded by a backbone curve that captures the envelope of the moment-rotation relationship during cyclic loading, defining the behavior of the plastic hinge
- Model requires 3 different calibration scenarios:
  1. Bare Steel Beams (Lignos and Krawinkler 2010)
  2. Composite Beams (Elkady and Lignos 2014)
  3. Columns (Lignos et al. 2019)

Key IMK parameters (Lignos and Krawinkler, 2010)

Strength Parameters:

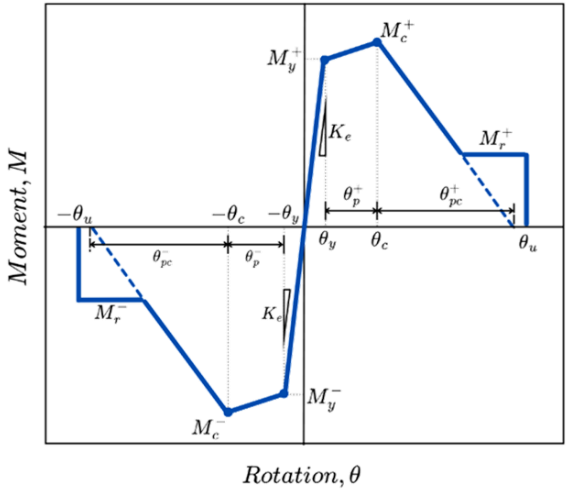
- Elastic stiffness (K_e)
- Effective Yield Moment (M_y)
- Capping Moment (M_c)
- Residual Moment (M_r)

Deformation Parameters:

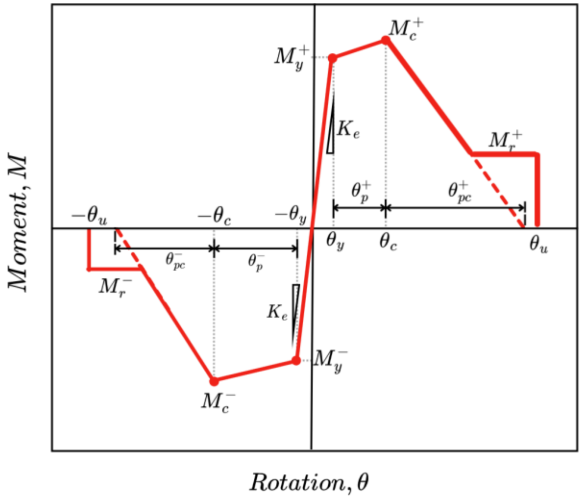
- Yield Rotation Loading (θ_y)
- Pre-capping Plastic Rotation (θ_p)
- Post Capping (θ_{pc})
- Ultimate Rotation Capacity (θ_u)

Deterioration Parameters:

- Beam web depth to thickness ratio (h/t_w)
- Beam flange width to thickness ratio ($b_f/2t_f$)
- Unbraced length (L_b)
- Radius of gyration (r_y)
- Member Length (L)
- Beam depth (d)
- Ultimate Rotation Capacity (θ_u)



Bare Steel Beams and Columns

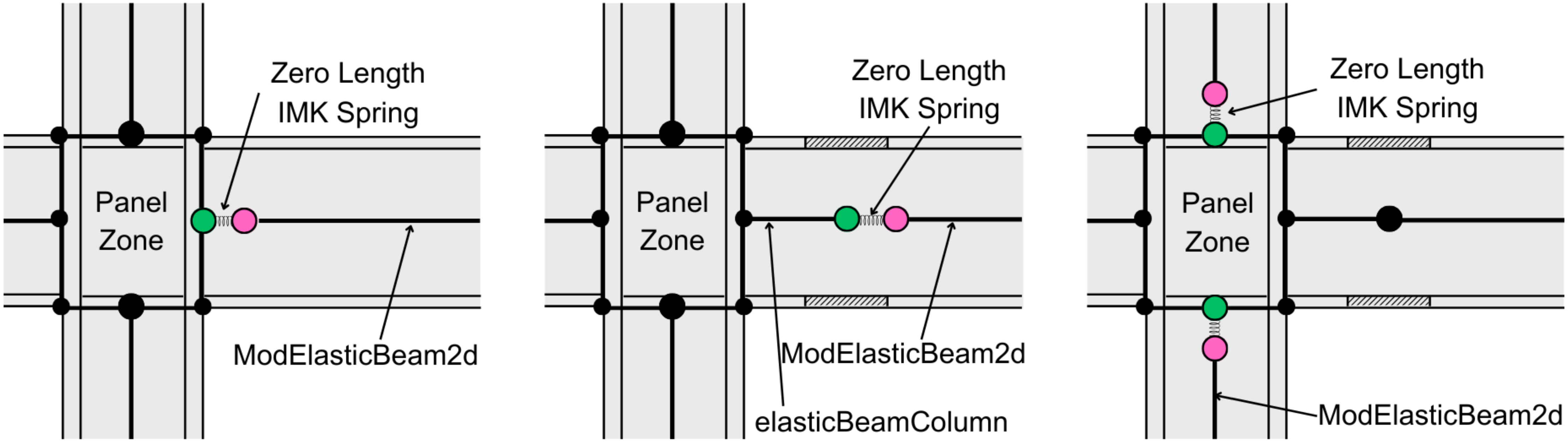


Composite Beams

Basic Nonlinear Regression:

$$RP = a_1 \cdot \left(\frac{h}{t_w}\right)^{a_2} \cdot \left(\frac{b_f}{2 \cdot t_f}\right)^{a_3} \cdot \left(\frac{L_b}{r_y}\right)^{a_4} \cdot \left(\frac{L}{d}\right)^{a_5} \cdot \left(\frac{c_{unit}^1 \cdot d}{533}\right)^{a_6} \cdot \left(\frac{c_{unit}^2 \cdot F_y}{355}\right)^{a_7}$$

IMK implementation



Non-RBS configuration

RBS Configuration

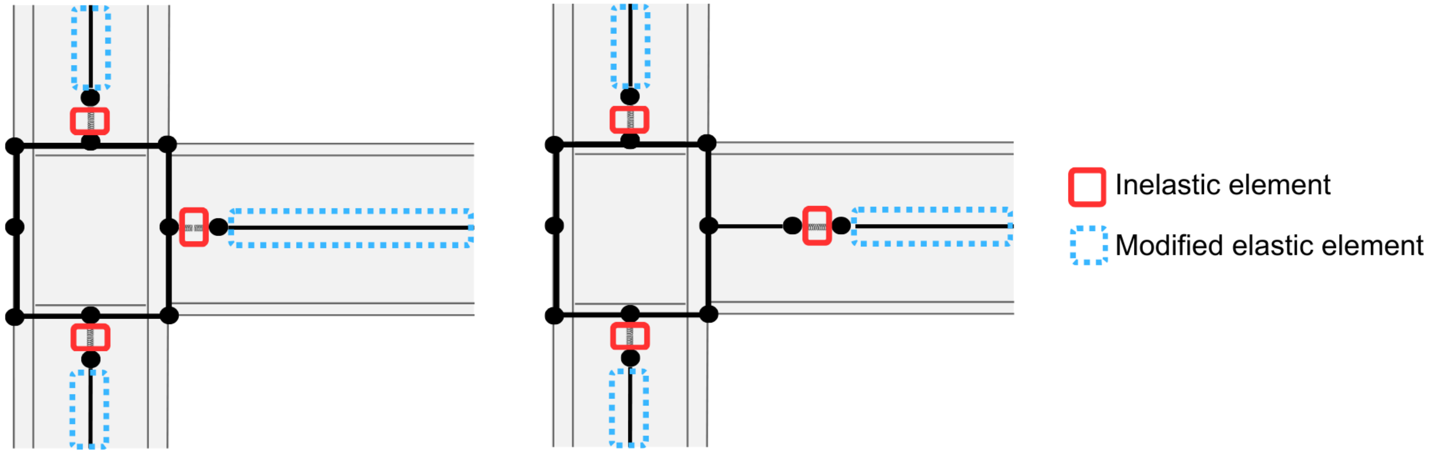
Column Configuration

🟩 i node 🟪 j node

Modeling Rayleigh-type damping

- Rayleigh damping is based on a combination of mass and stiffness proportional damping
- As damage increases, damping increases and stiffness decreases
- Time invariant stiffness matrix
  - For elastic members stiffness proportional damping is increased through modifications
  - Inelastic members are not given stiffness proportional damping and are calibrated to desired nonlinear model

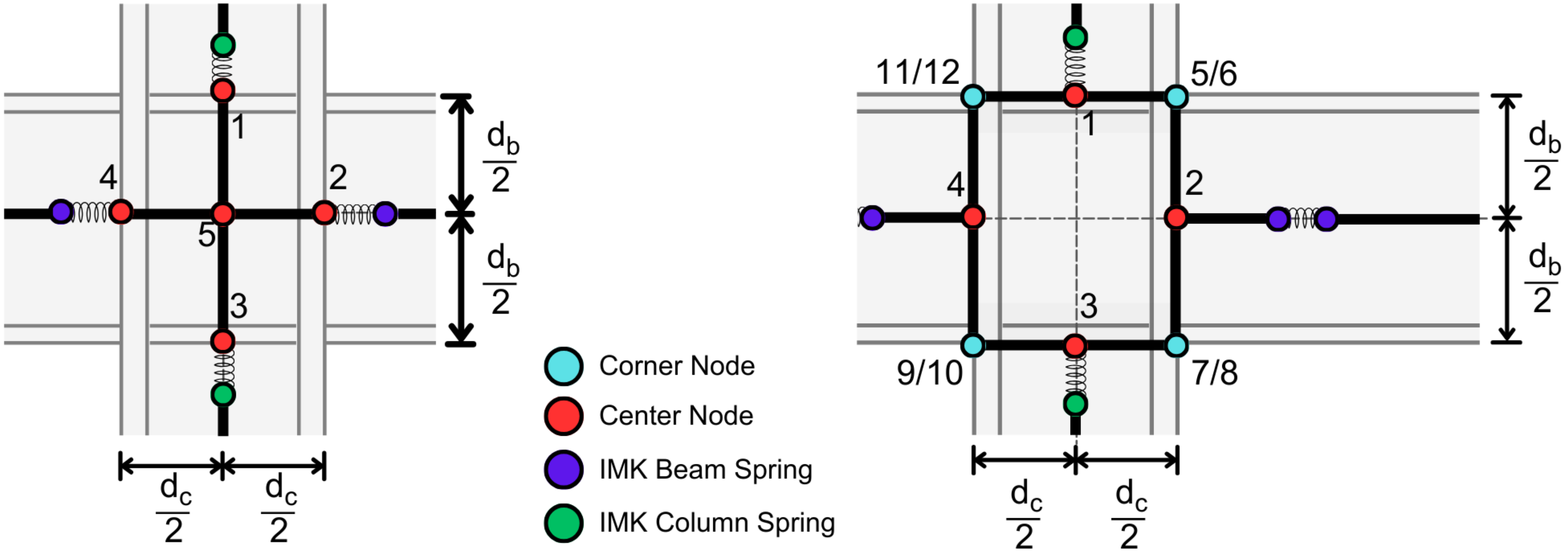
(Zareian and Medina, 2010)



Non-RBS Configuration

RBS Configuration

Panel zone models



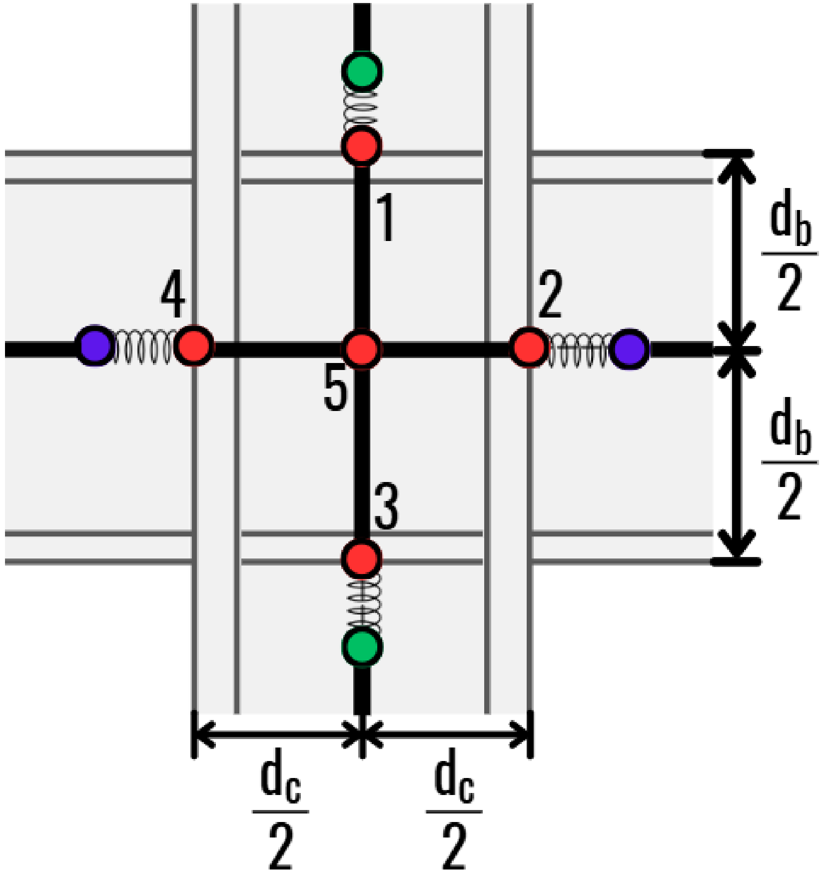
Joint2d panel zone

- Assumes rigid panel zone
- Consists of 5 nodes and 2 link elements

Advanced panel zone

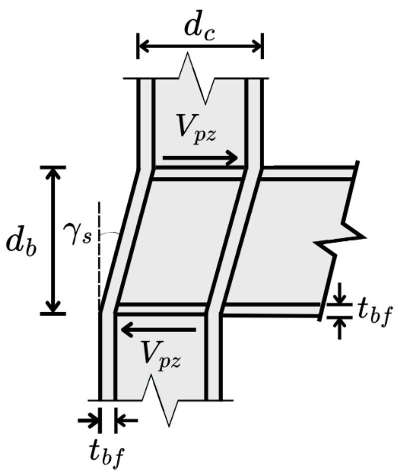
- Incorporates bending and shear deformation
- Consists of 12 nodes and 8 link elements

Joint2d panel zone model

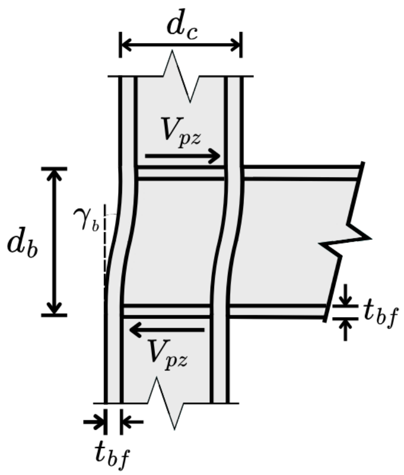


- Assumes panel zone remains rigid
- Ignores the effects of doubler plates
- RBS is not modeled away from column face

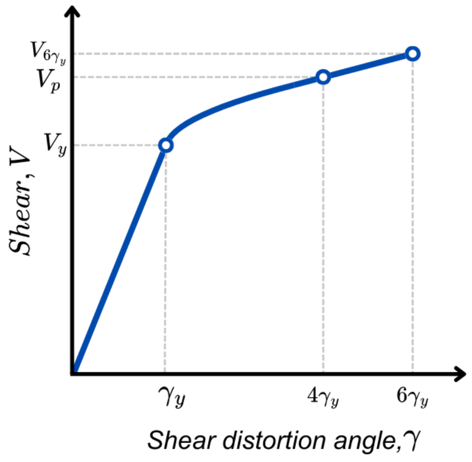
Advanced panel zone model



Shear deformation



Bending deformation

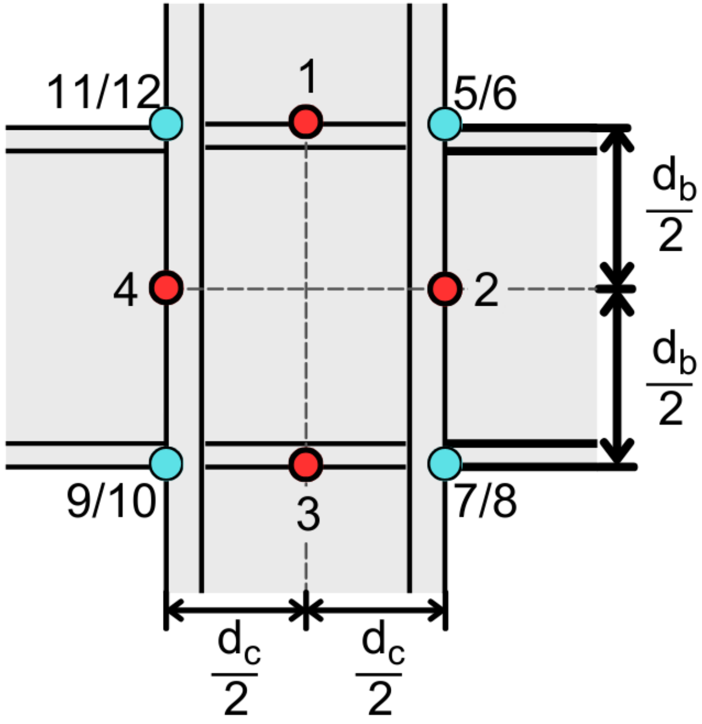


Trilinear panel zone parameters

- Creates the hysteretic response for the panel zone
- Key features:
  - Based on structural mechanics to reflect realistic stress distributions within the panel zone joint (Skiadopoulos et al., 2021)
  - Addresses limitations in panel zone geometry configurations (Skiadopoulos et al., 2021)
  - Considers bending and shear deformation in the panel zone (Skiadopoulos et al., 2021)

Advanced panel zone basic construction

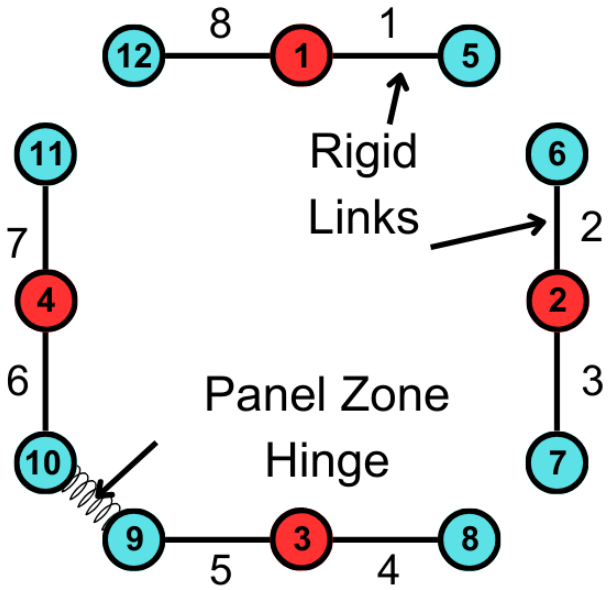
- Panel zone nodes
  - Placement dictated by surrounding beams and columns
- Rigid elastic links between nodes



Panel zone general geometry

● Corner Node

● Center Node



Panel zone breakdown and configuration

Validation

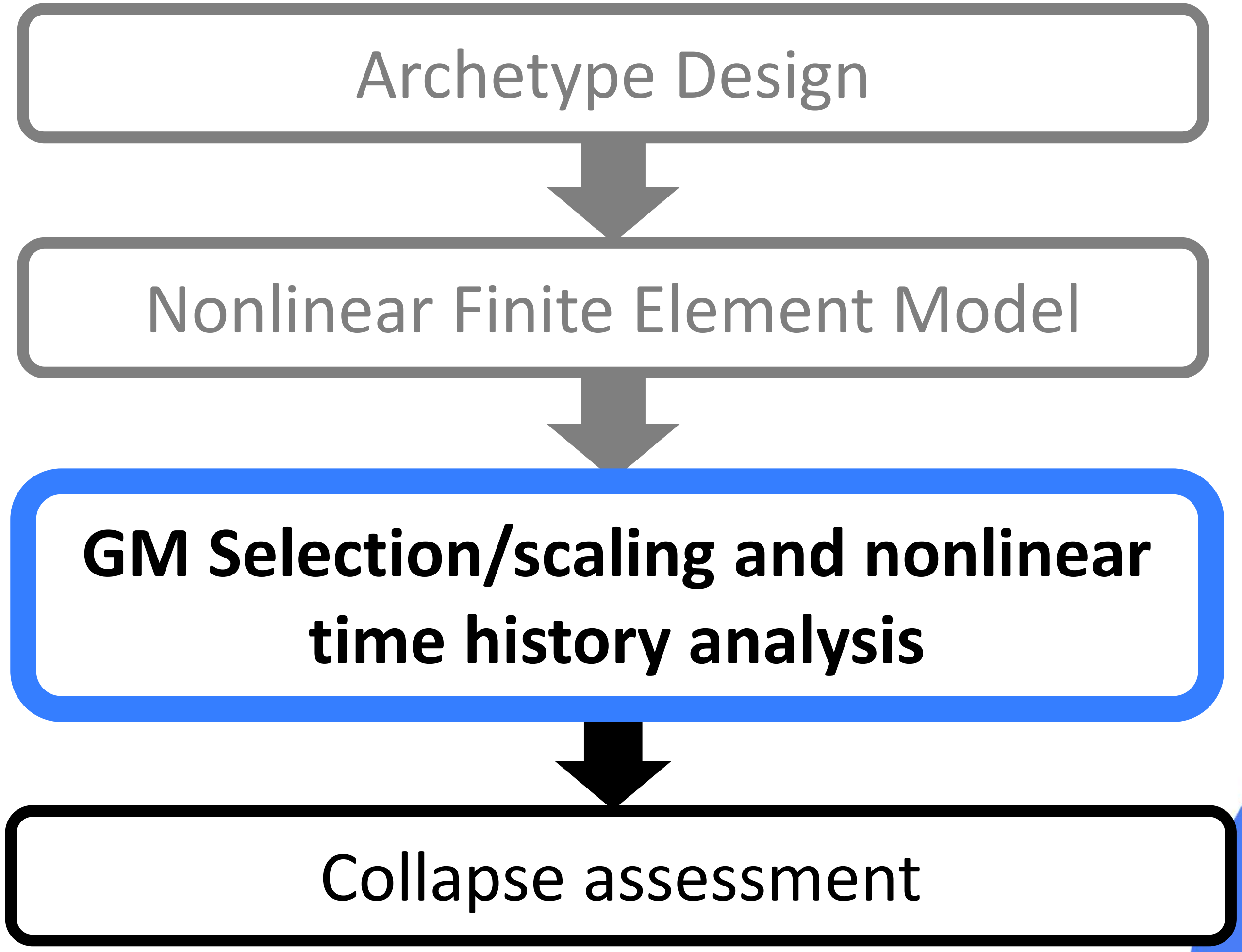
SAP Models versus OpenSees SMRF Model

Mode	SAP Models, Period (s)	Opensees model, Period (s)	Difference
1	0.3397	0.3309	3%
2	0.1256	0.1226	2%
3	0.0579	0.0558	4%
4	0.0398	0.0378	5%

Fundamental period comparison for panel zone models

Archetypes	Advanced Panel Zone period (s)	Joint2D Panel Zone period (s)	Difference
2-story	0.701	0.686	2%
4-story	0.927	0.838	10%
8-story	1.725	1.541	11%

Methodology

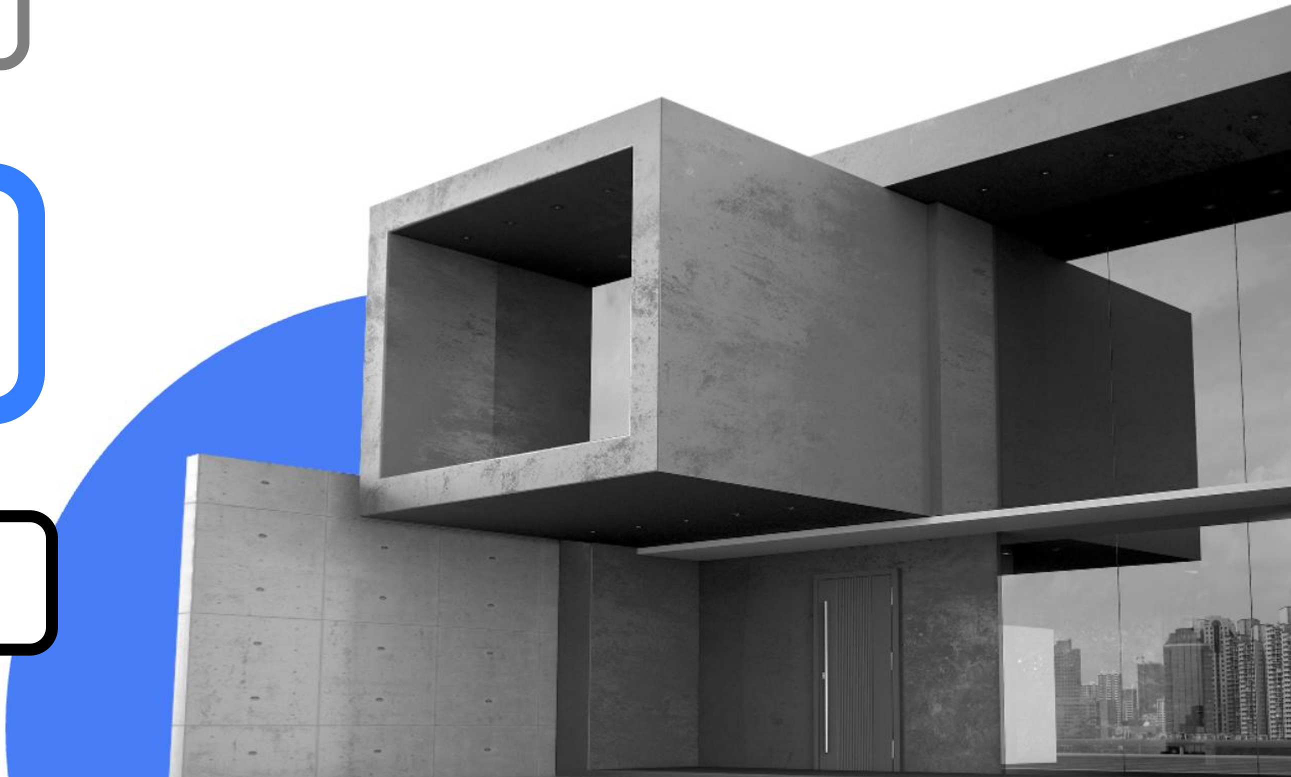


Archetype Design

Nonlinear Finite Element Model

GM Selection/scaling and nonlinear time history analysis

Collapse assessment



GM Selection Criteria

Normal Fault GM

Distance: 0-45 km

Magnitude: 5.5-8.0

Large Magnitude GM

Distance: 0-30 km

Magnitude: 6.5-8.0

Site Class B

V_{S30}: 600-1550 m/s

Number of GM components: 168

Site Class D

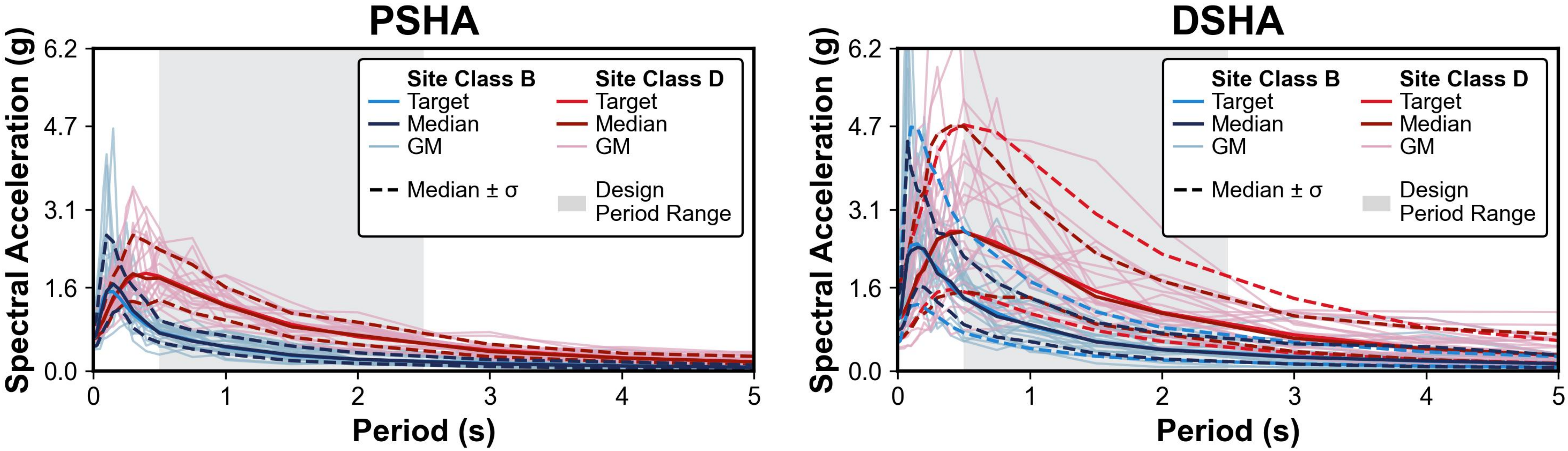
V_{S30}: 200-325 m/s

Number of GM components: 278

GM obtained from NGA-West2 database (Ancheta et al. 2014)

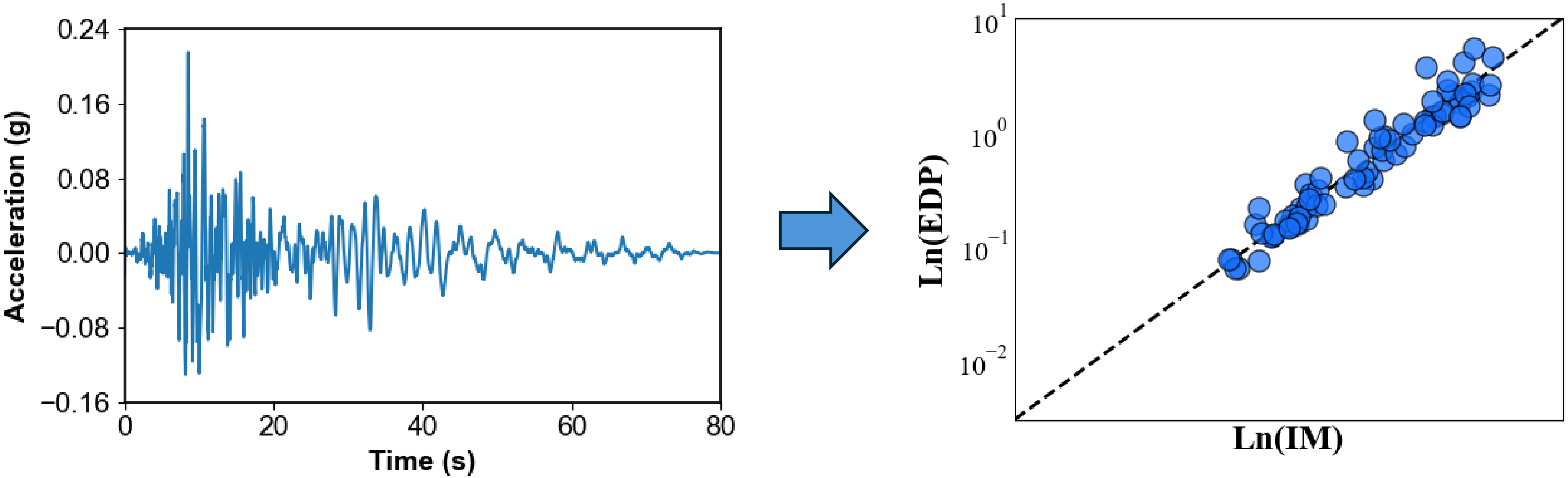
GM Scaling

- Scaled using SigmaSpectra (Kottke and Rathje, 2008)
- 20 GM for Site Classes B and D
- Period Range of Interest ⟶ 1 to 3 seconds



Cloud Analysis

- Model is subjected to a suite (“cloud”) of GM records
- Engineering demand parameters (EDPs) are recorded during nonlinear dynamic time-history analysis
- EDPs are connected to seismic intensity measure (IM) using linear regression



Methodology

Archetype Design

Nonlinear Finite Element Model

GM Selection/Scaling and nonlinear time history analysis

Collapse assessment

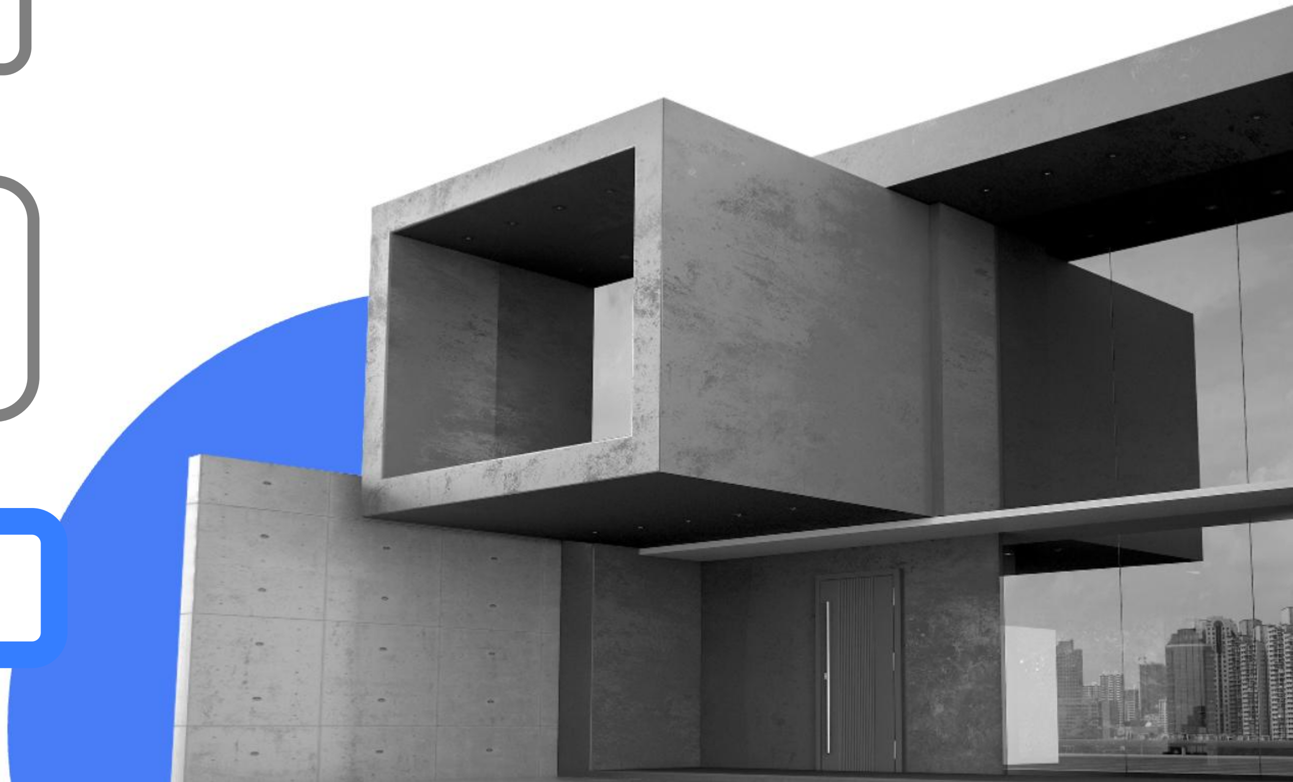
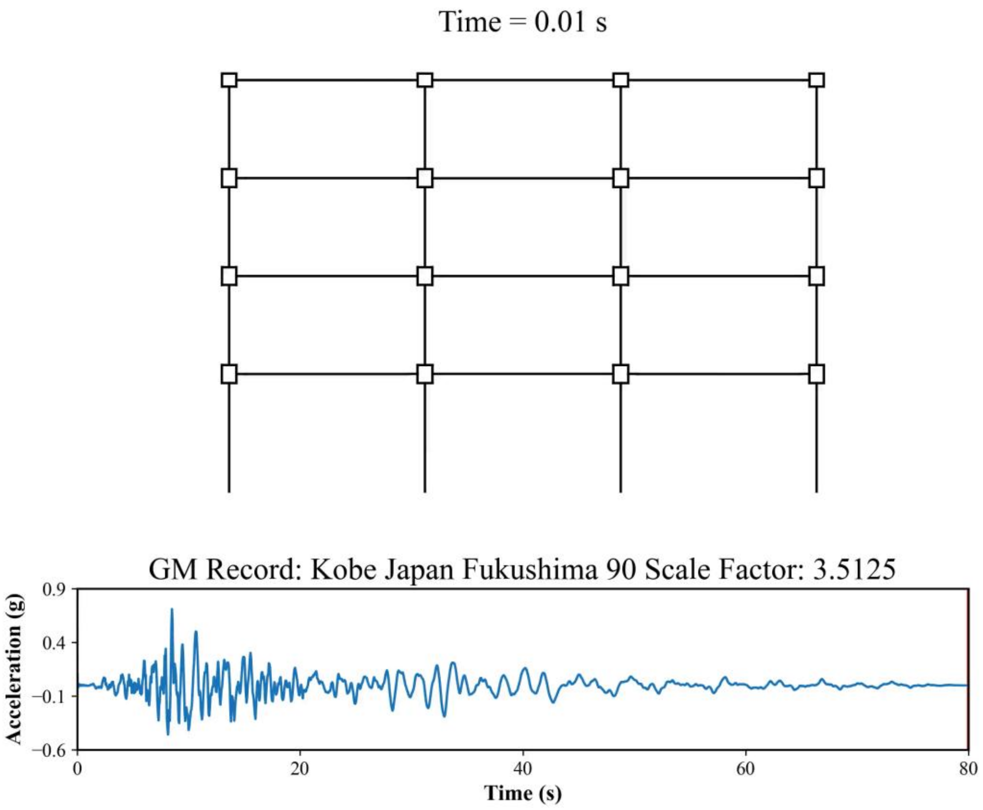
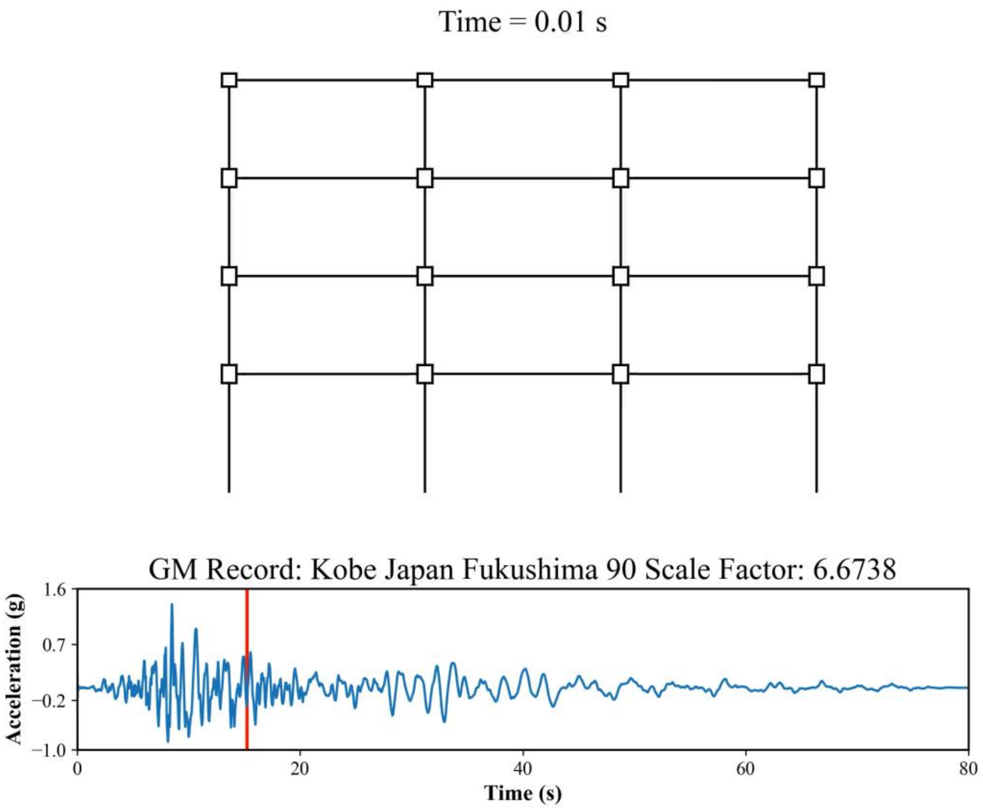


Illustration of collapse mechanism

PSHA

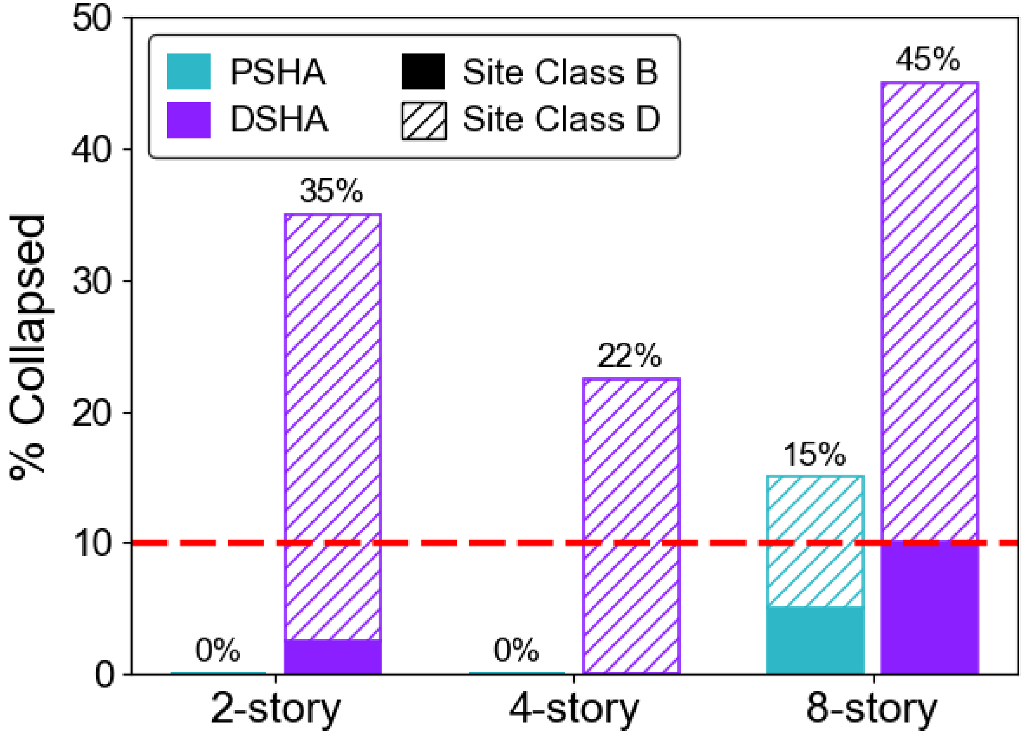


DSHA

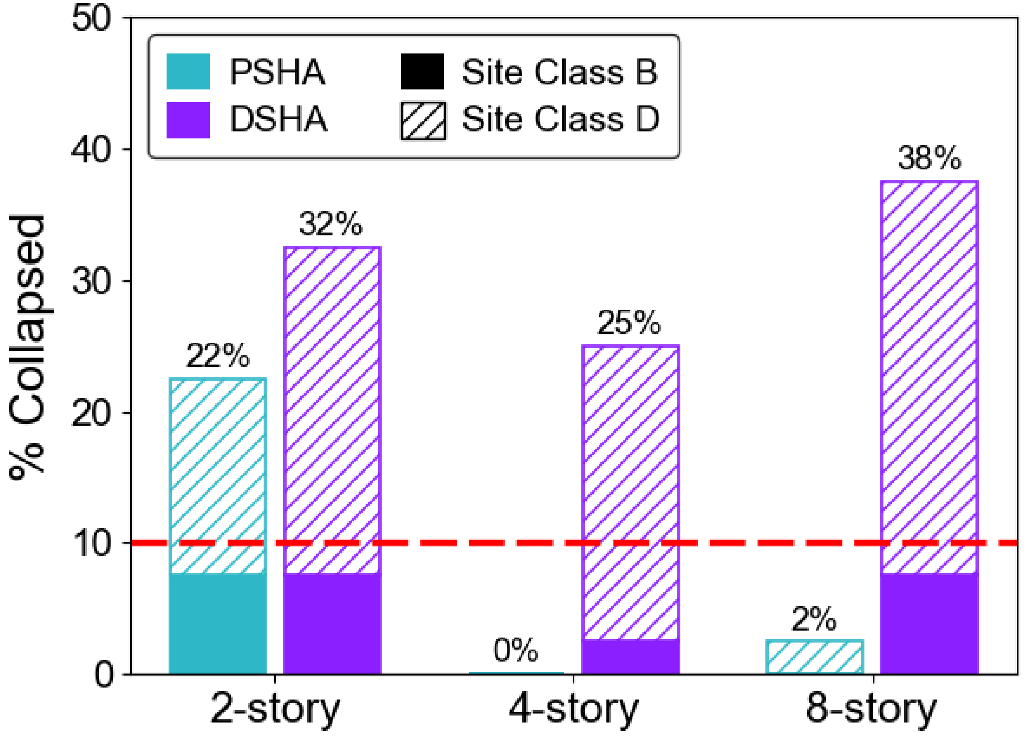


Collapse under MCE

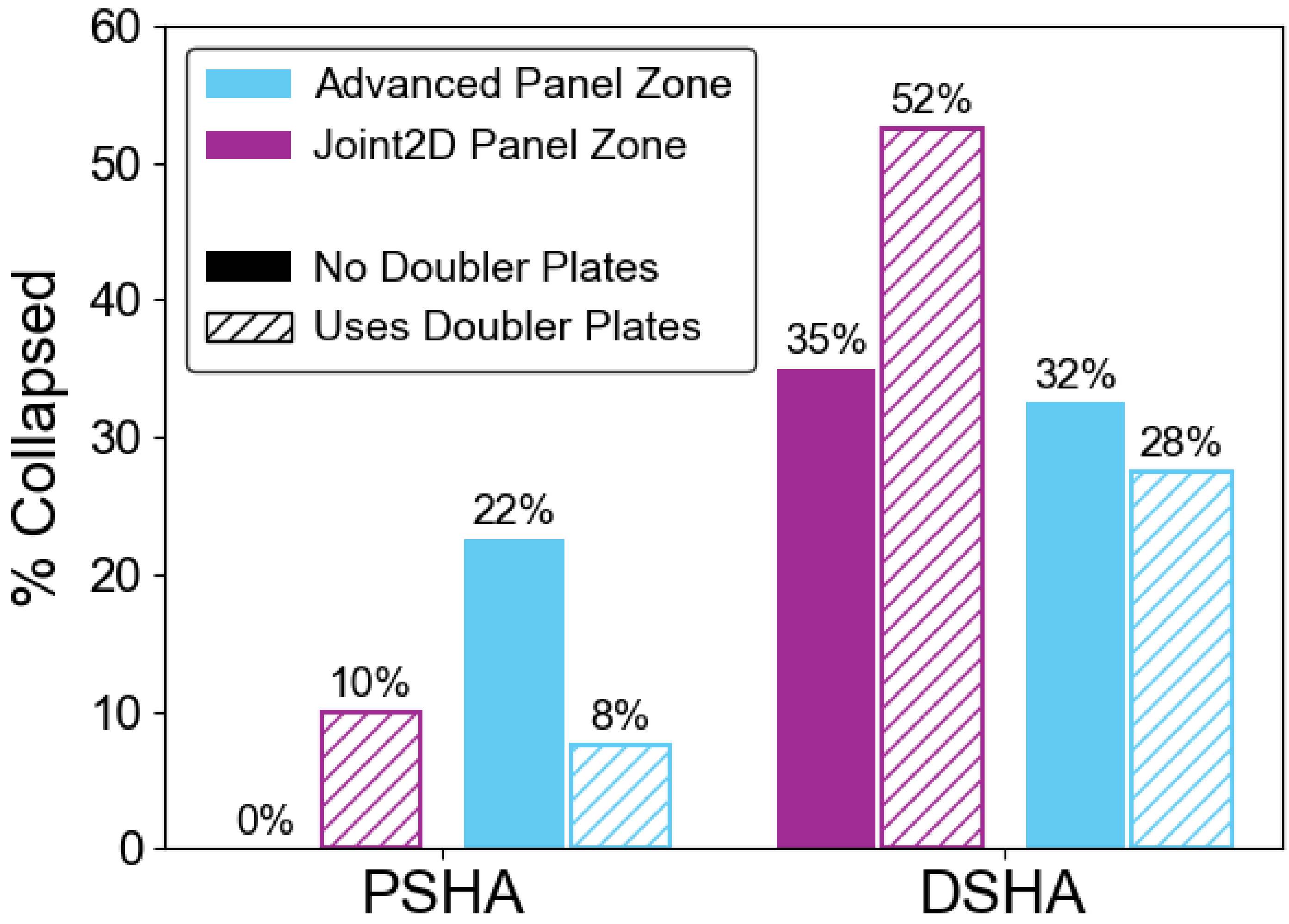
Joint2D Panel Zone



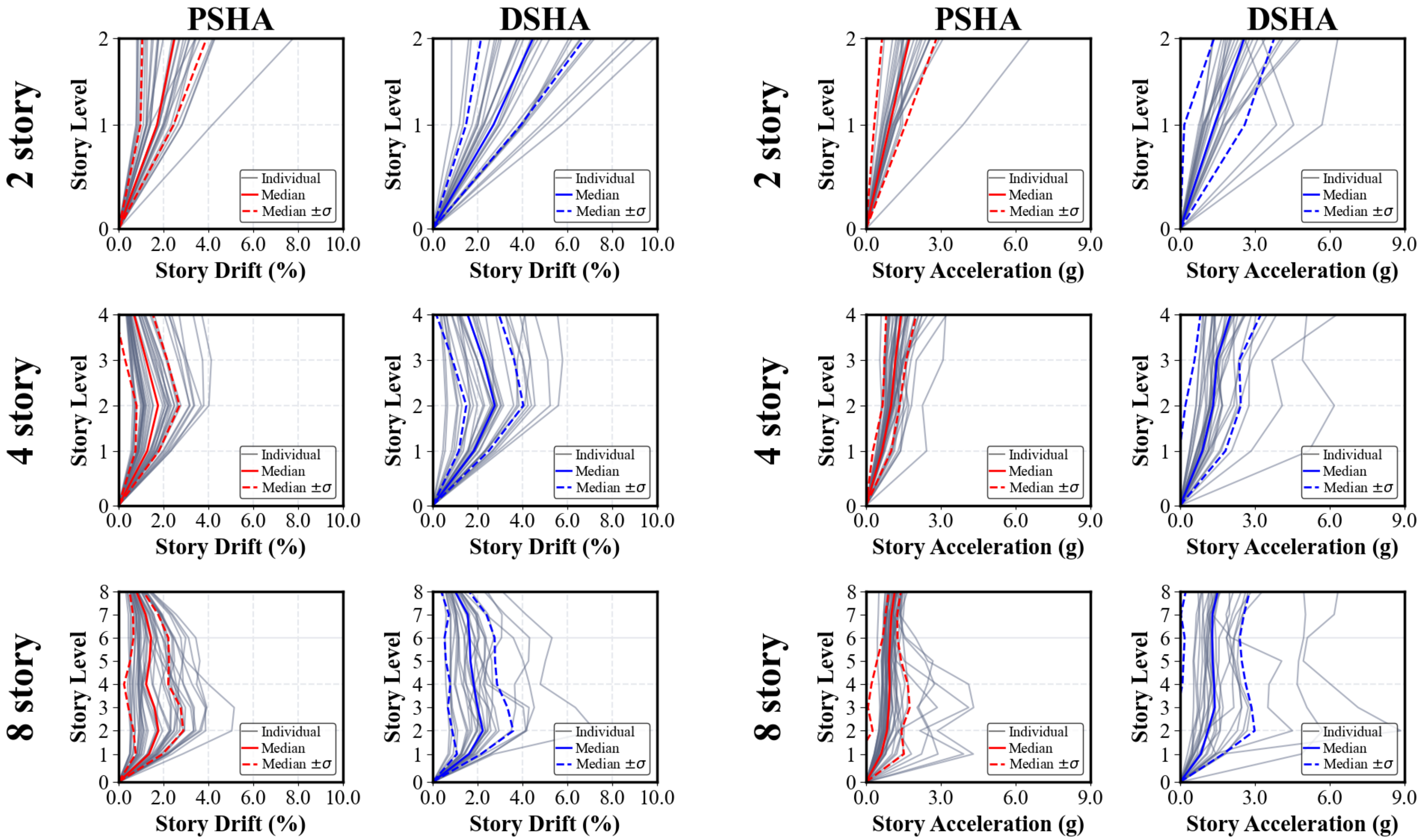
Advanced Panel Zone



Doubler plate effects



Drift and acceleration profiles for advanced panel zone models



Conclusion

- DSHA **exceeds 10% collapse** under MCE GM by **2.5 to 4 times** independent of panel zone model
- Buildings designed for **site class D** under DSHA Site Class D GM are **5-6 times** beyond code life expectancy collapse levels
- PSHA exceeds life safety when:
  - 2-story advanced panel zone model has convergence issues at specific intensity level
  - 8-story uses doubler plates but the joint2d model does not account for those
- The 8-story archetype is the most suspectable to collapse under DSHA GM, the 4-story is the least suspectable

Future research and a call for collaboration

- Near-field effects due to proximity to the fault (current limitation)
- Translate structural responses into risk-based and loss analysis
- Impact of designing for deterministic scenario?

Mission: Develop **Utah-specific** fragility function for different structural systems

- Industry experts input to develop archetype buildings
- Research support and collaboration
- Interested? Send email to: Mohsen.Zaker@usu.edu or scan the QR code:

UEEC Focus Areas

Promoting resiliency and rapid recovery following a large earthquake by focusing on:

Education & Training

- ✓ Train a new generation of earthquake engineers and develop Utah's first graduate-level earthquake engineering emphasis area.
- ✓ Provide in-person and online training for working engineers in areas of seismic design provisions and post-earthquake building inspection.
- ✓ Facilitate technology transfer and training on seismic design and retrofitting to benefit Utah's transportation, water, energy, and telecom sectors.

Engineering Solutions

- ✓ Develop Utah-specific solutions to Utah-specific problems that reduce time and costs associated with hardening our buildings and infrastructure.
- ✓ Provide seismic risk evaluations to prioritize which vulnerabilities to fix first and how to design new buildings and infrastructure better the first time.
- ✓ Focus efforts aimed at fixing Utah's overwhelming number of deadly unreinforced masonry buildings, homes and schools.

Resilient Recovery

- ✓ Serve the people of Utah as the state's trusted leader in engineering for resiliency and rapid recovery time following an earthquake.
- ✓ Encourage investment in our future: national studies show that every $1 spent on disaster mitigation saves $6 in future recovery costs.
- ✓ Help Utah navigate FEMA's new seismic design standards that will focus on minimizing functional recovery time following an earthquake.

Recent Webinar on ASCE 7-22 Site Classification

Best Practices for Shear Wave Velocity Measurements to Support Vs30 Site Classification or Site-Specific Site Response Analyses Consistent with ASCE 7-22

Brady R. Cox, Ph.D., P.E.
Professor
Utah State University
Founding Director, Utah Earthquake Engineering Center

EERI San Diego Chapter Webinar
Site Characterization Using Vs30 Per the ASCE 7-22
14 January 2026

+400 participants

UtahState University
CIVIL AND ENVIRONMENTAL ENGINEERING

Earthquake Engineering Research Institute
Dedicated to increasing earthquake resilience

ASCE 7-22 Chapter 20

ASCE STANDARD

ASCE/SEI

7-22

Minimum Design Loads and Associated Criteria for Buildings and Other Structures

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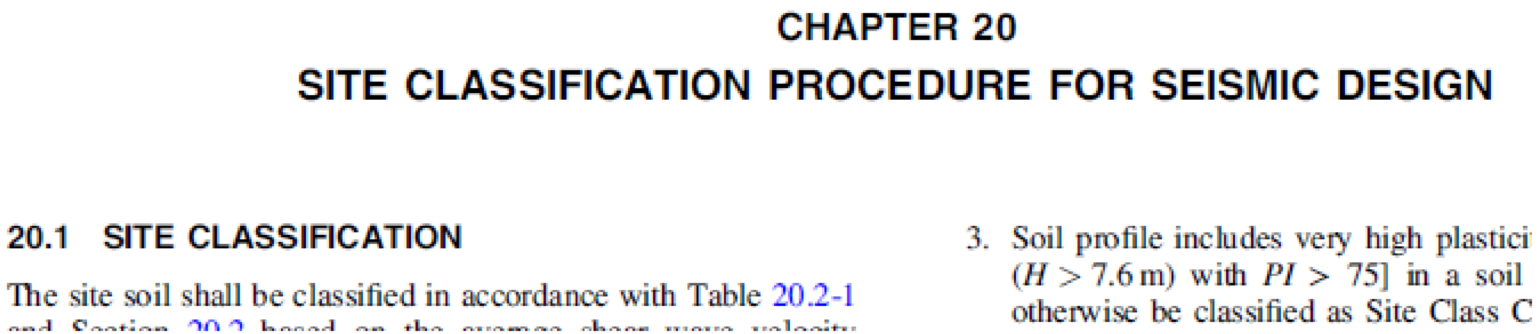
With the adoption of ASCE 7-22 seismic site classification now <u>requires</u> shear wave velocity (Vs) measurements AND three new site classes have been added



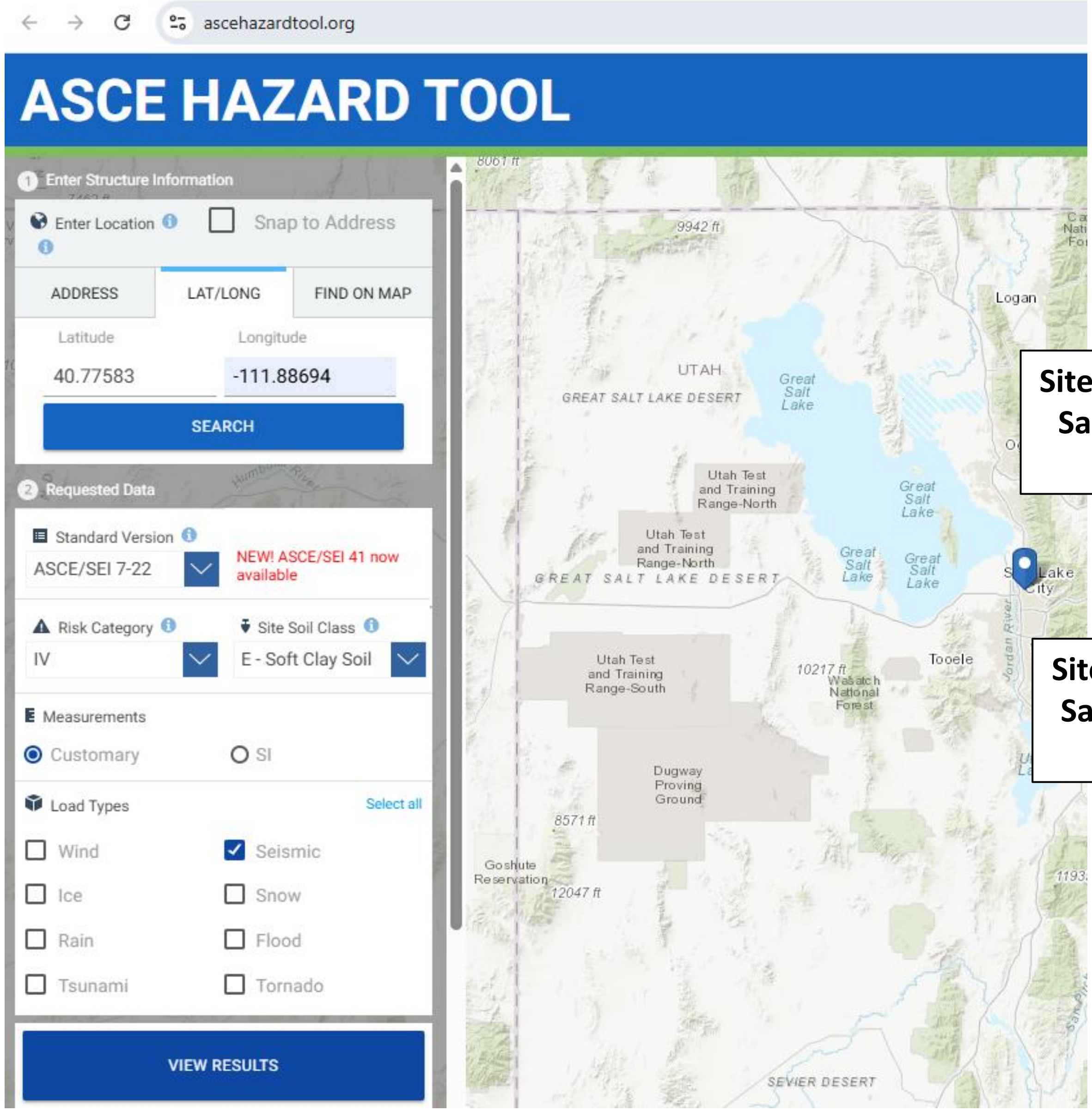
CHAPTER 20
SITE CLASSIFICATION PROCEDURE FOR SEISMIC DESIGN

20.1 SITE CLASSIFICATION

The site soil shall be classified in accordance with Table 20.2-1 and Section 20.2 based on the average shear wave velocity

3. Soil profile includes very high plastici
$(H > 7.6\ \text{m})$ with $PI > 75$] in a soil
otherwise be classified as Site Class C

Two-Period MCE$_R$ Spectra



ascehazardtool.org

ASCE HAZARD TOOL

1 Enter Structure Information

Enter Location ☐ Snap to Address

ADDRESS | LAT/LONG | FIND ON MAP

Latitude: 40.77583

Longitude: -111.88694

SEARCH

2 Requested Data

Standard Version: ASCE/SEI 7-22

NEW! ASCE/SEI 41 now available

Risk Category: IV

Site Soil Class: E - Soft Clay Soil

Measurements: ● Customary ○ SI

Load Types (Select all)

☐ Wind ☑ Seismic

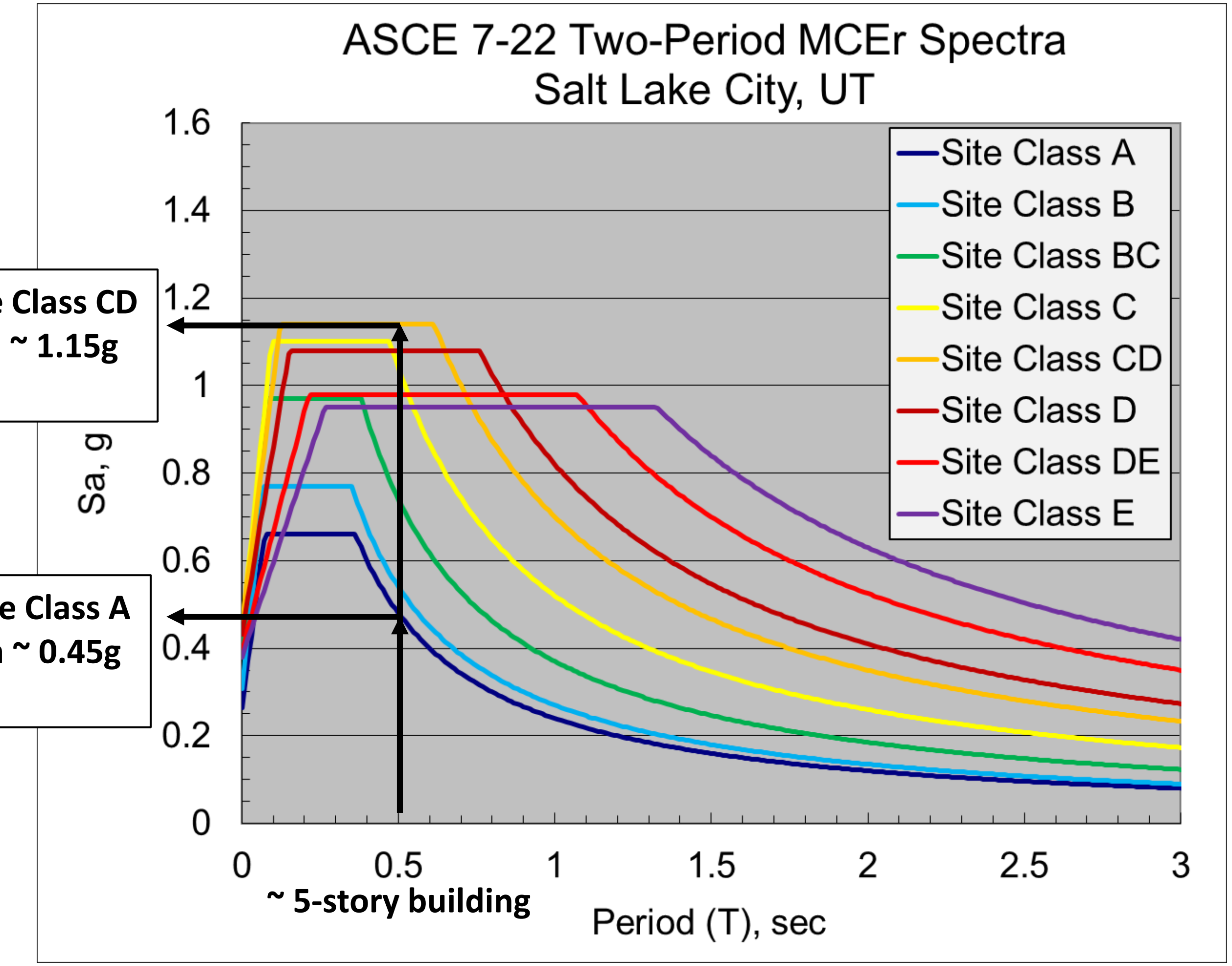
☐ Ice ☐ Snow

☐ Rain ☐ Flood

☐ Tsunami ☐ Tornado

VIEW RESULTS

https://ascehazardtool.org/

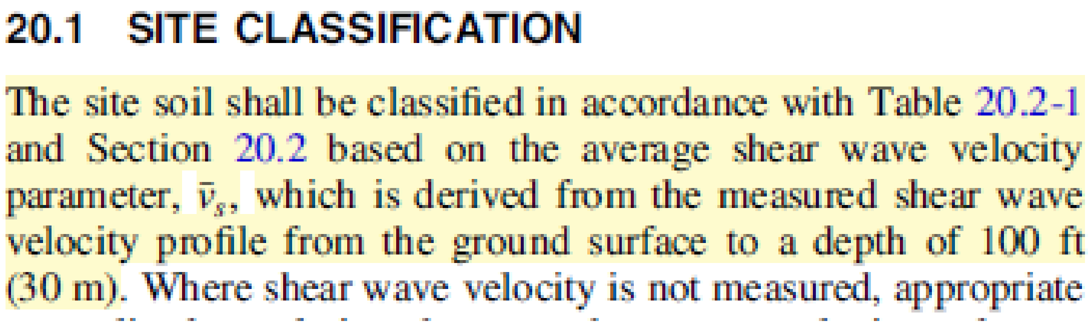


Site Class CD
Sa ~ 1.15g

Site Class A
Sa ~ 0.45g

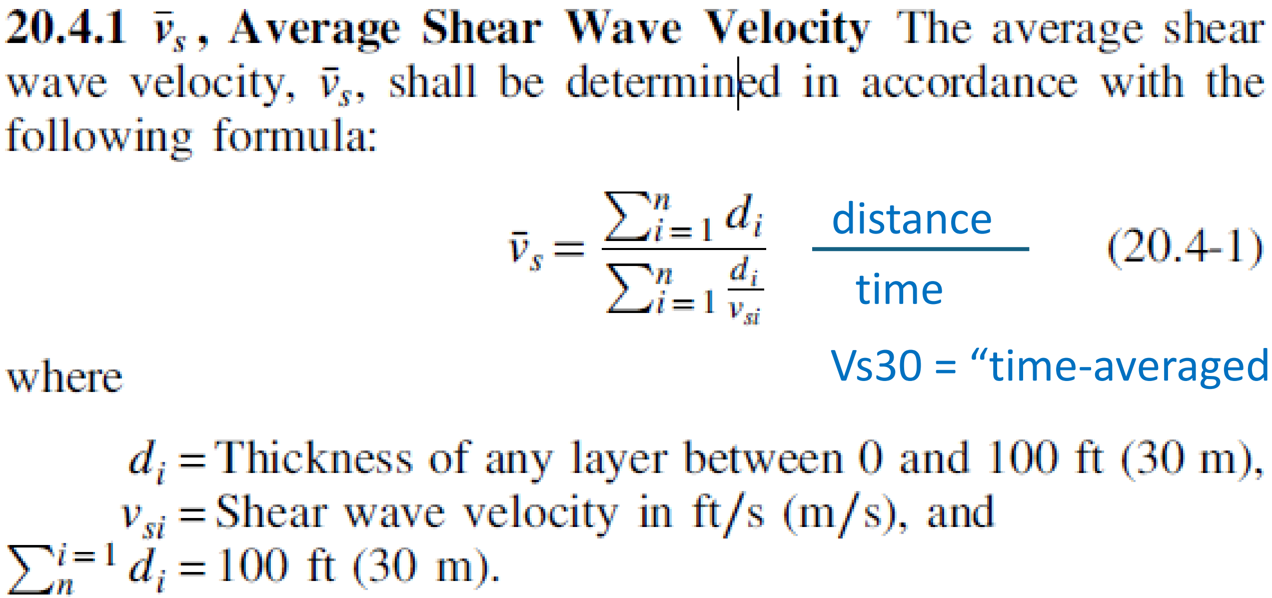
~ 5-story building

Vs30… or $\bar{V}s$



20.1 SITE CLASSIFICATION

The site soil shall be classified in accordance with Table 20.2-1 and Section 20.2 based on the average shear wave velocity parameter, $\bar{v}_s$, which is derived from the measured shear wave velocity profile from the ground surface to a depth of 100 ft (30 m). Where shear wave velocity is not measured, appropriate



20.4.1 $\bar{v}_s$, Average Shear Wave Velocity The average shear wave velocity, $\bar{v}_s$, shall be determined in accordance with the following formula:

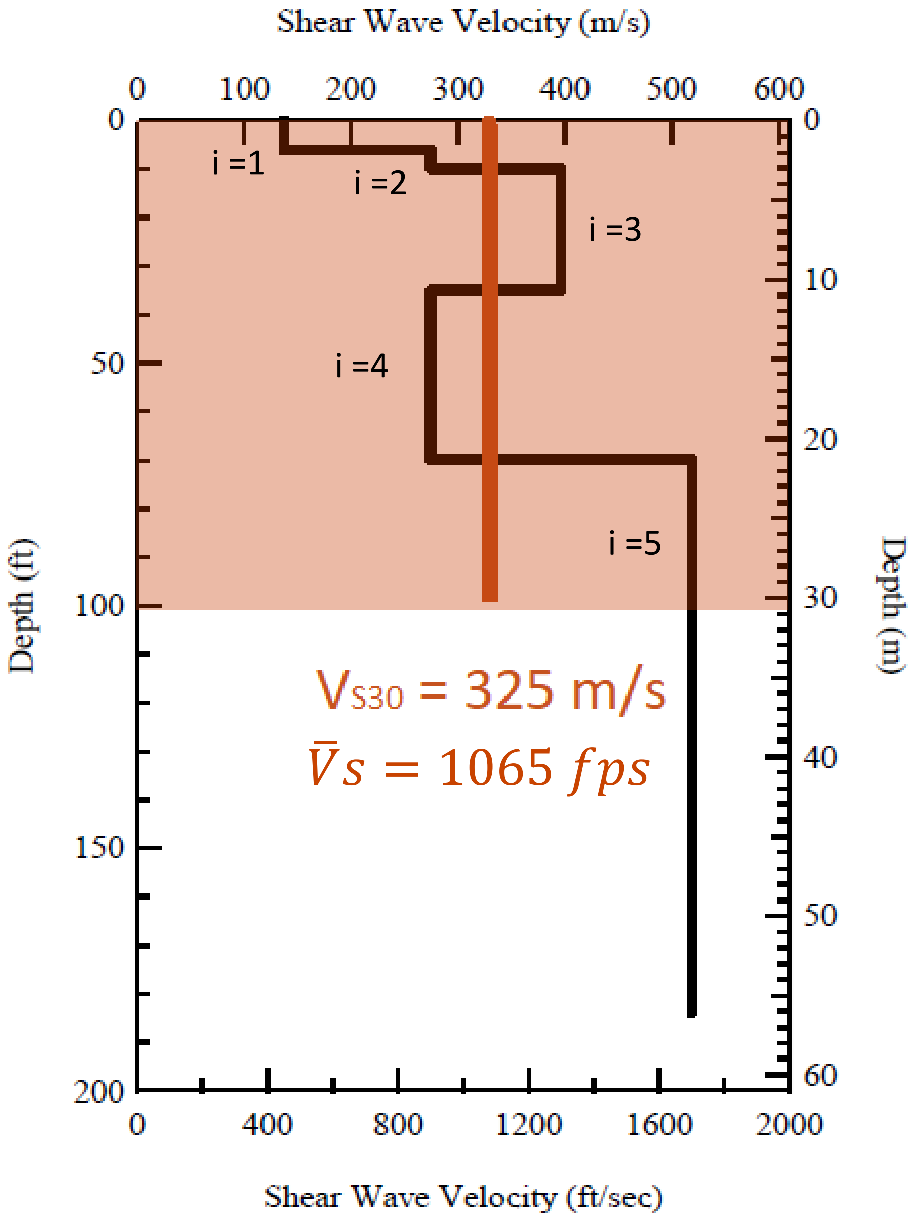
$$\bar{v}_s = \frac{\sum_{i=1}^{n} d_i}{\sum_{i=1}^{n} \frac{d_i}{v_{si}}} \qquad (20.4\text{-}1)$$

$$\frac{\text{distance}}{\text{time}}$$

Vs30 = “time-averaged” Vs

where

d_i = Thickness of any layer between 0 and 100 ft (30 m),
v_{si} = Shear wave velocity in ft/s (m/s), and
$\sum_{n}^{i=1} d_i$ = 100 ft (30 m).



Vs30 = 325 m/s

$\bar{V}s = 1065\ fps$

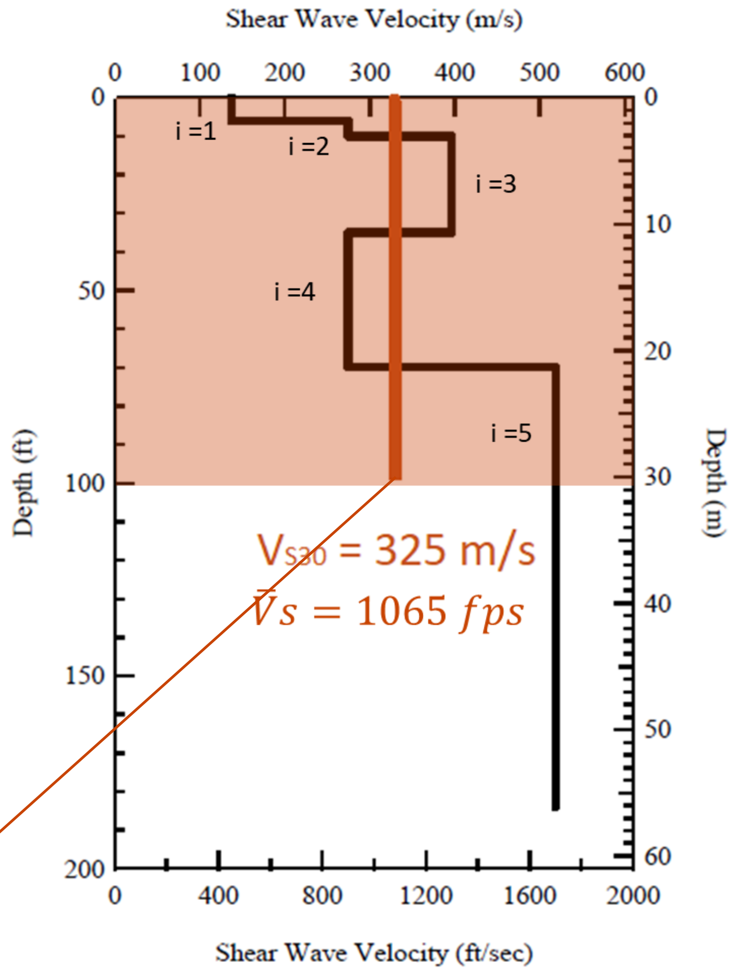
Seismic Site Classification

20.1 SITE CLASSIFICATION

The site soil shall be classified in accordance with Table 20.2-1 and Section 20.2 based on the average shear wave velocity parameter, $\bar{v}_s$, which is derived from the measured shear wave velocity profile from the ground surface to a depth of 100 ft (30 m). Where shear wave velocity is not measured, appropriate

Table 20.2-1. Site Classification.

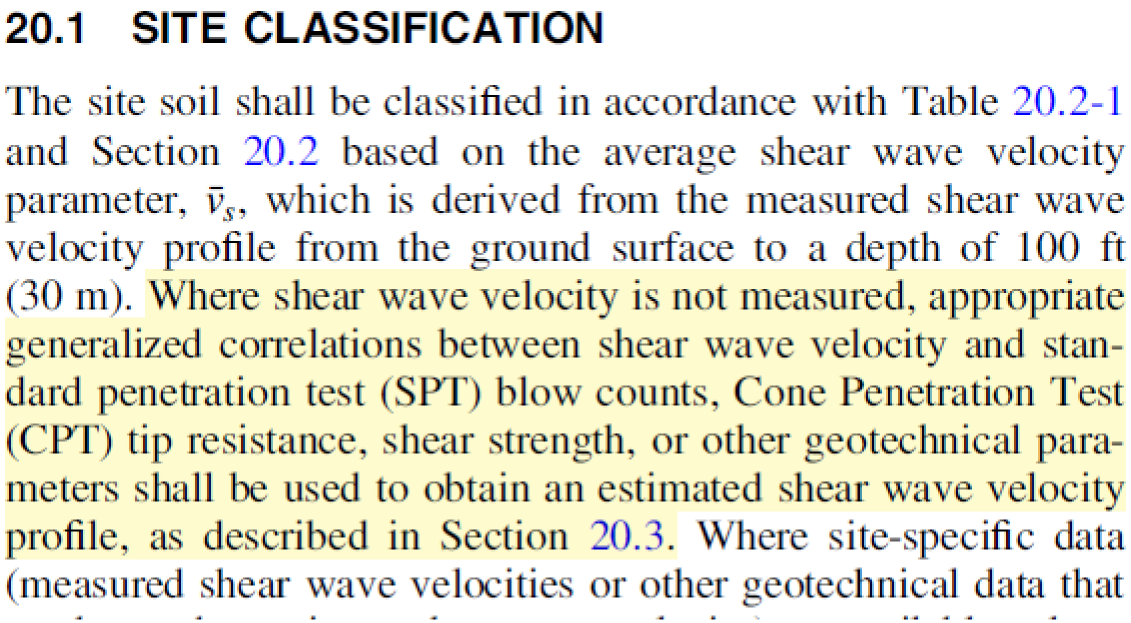
Site Class	Vs30	$\bar{v}_s$ Calculated Using Measured or Estimate Shear Wave Velocity Profile (ft/s)
A. Hard rock	>1500 m/s	>5,000
B. Medium hard rock	915 to 1500 m/s	>3,000 to 5,000
BC. Soft rock	640 to 915 m/s	>2,100 to 3,000
C. Very dense sand or hard clay	440 to 640 m/s	>1,450 to 2,100
CD. Dense sand or very stiff clay	305 to 440 m/s	>1,000 to 1,450
D. Medium dense sand or stiff clay	215 to 305 m/s	>700 to 1,000
DE. Loose sand or medium stiff clay	150 to 215 m/s	>500 to 700
E. Very loose sand or soft clay	> 150 m/s	≥500
F. Soils requiring site response analysis in accordance with Section 21.1		See Section 20.2.1



V_{S30} = 325 m/s

$\bar{V}s = 1065\ fps$

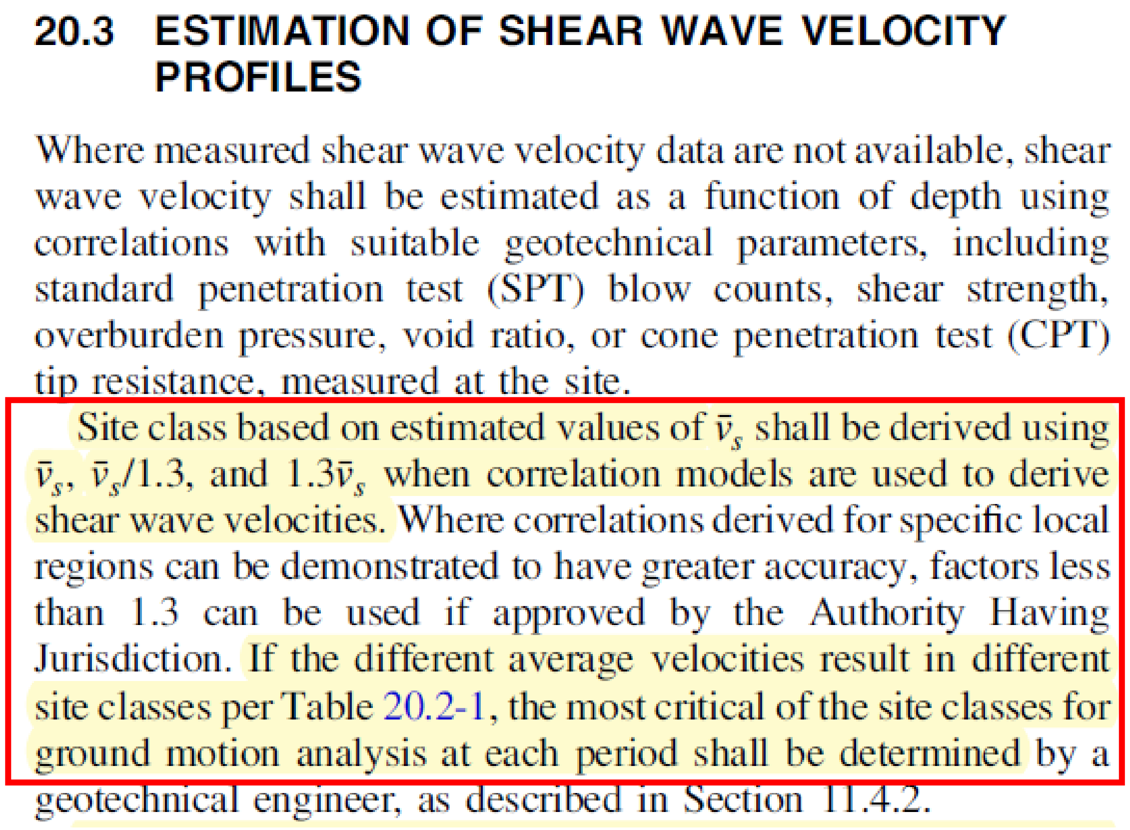
Seismic Site Classification without Vs Measurements



20.1 SITE CLASSIFICATION

The site soil shall be classified in accordance with Table 20.2-1 and Section 20.2 based on the average shear wave velocity parameter, $\bar{v}_s$, which is derived from the measured shear wave velocity profile from the ground surface to a depth of 100 ft (30 m). Where shear wave velocity is not measured, appropriate generalized correlations between shear wave velocity and standard penetration test (SPT) blow counts, Cone Penetration Test (CPT) tip resistance, shear strength, or other geotechnical parameters shall be used to obtain an estimated shear wave velocity profile, as described in Section 20.3. Where site-specific data (measured shear wave velocities or other geotechnical data that

- **Making good Vs measurements is important!**
- **Professor Brady Cox is willing to discuss best practices for Vs30 site classification with SEAU**



20.3 ESTIMATION OF SHEAR WAVE VELOCITY PROFILES

Where measured shear wave velocity data are not available, shear wave velocity shall be estimated as a function of depth using correlations with suitable geotechnical parameters, including standard penetration test (SPT) blow counts, shear strength, overburden pressure, void ratio, or cone penetration test (CPT) tip resistance, measured at the site.

Site class based on estimated values of $\bar{v}_s$ shall be derived using $\bar{v}_s$, $\bar{v}_s/1.3$, and $1.3\bar{v}_s$ when correlation models are used to derive shear wave velocities. Where correlations derived for specific local regions can be demonstrated to have greater accuracy, factors less than 1.3 can be used if approved by the Authority Having Jurisdiction. If the different average velocities result in different site classes per Table 20.2-1, the most critical of the site classes for ground motion analysis at each period shall be determined by a geotechnical engineer, as described in Section 11.4.2.

The Penalty

References

Abrahamson, N. A. (2000). *State of the practice of seismic hazard evaluation*. Proceedings of the GeoEng 2000 Conference, Melbourne, Australia, 19–24.

Applied Technology Council (ATC). (2017). *Guidelines for nonlinear structural analysis for design of buildings, Part IIa – Steel moment frames*. National Institute of Standards and Technology, NIST GCR 17-917-46v2, 139 pp., https://doi.org/10.6028/NIST.GCR.17-917-46v2.

American Society of Civil Engineers (ASCE). (2017). *Minimum design loads and associated criteria for buildings and other structures* (ASCE/SEI 7-16). Reston, VA: American Society of Civil Engineers.

American Society of Civil Engineers (ASCE). (2022). *Minimum design loads and associated criteria for buildings and other structures (ASCE/SEI 7-22)*. Reston, VA.

American Institute of Steel Construction (AISC). (2022a). *Specification for structural steel buildings (AISC 360-22)*. Chicago, IL.

American Institute of Steel Construction (AISC). (2022b). *Seismic provisions for structural steel buildings (AISC 341-22)*. Chicago, IL.

American Institute of Steel Construction (AISC). (2022c). *Prequalified connections for special and intermediate steel moment frames for seismic applications (AISC 358-22)*. Chicago, IL.

Baker, J. W. (2015). *Efficient analytical fragility function fitting using dynamic structural analysis*. Earthquake Spectra, 31(1), 579–599

Baker, J. W., Bradley, B. A., and Stafford, P. J. (2021). “Seismic risk" and "Ground-motion selection." *Seismic hazard and risk analysis*, Cambridge University Press, 369–446. https://doi.org/10.1017/9781108425056

Bowman, S., et al. (2022). *Putting Down Roots in Earthquake Country: Your Handbook for Earthquakes in Utah.* Utah Seismic Safety Commission. https://ugspub.nr.utah.gov/publications/non_lib_pubs/putting-down-roots.pdf.

Computers and Structures, Inc. (CSI). (2016). *SAP2000: Integrated software for structural analysis and design* [Computer software]. Version 18.2.0, Berkeley, CA.

Deierlein, G. G., Krawinkler, H., and Cornell, C. A. (2003). *A framework for performance-based earthquake engineering*. Proceedings of the 2003 Pacific Conference on Earthquake Engineering, Pacific Earthquake Engineering Research Center (PEER), Berkeley, CA.

.

Hamburger, R. O., Krawinkler, H., Malley, J. O., and Adan, S. M. (2009). *Seismic design of steel special moment frames: A guide for practicing engineers.* NEHRP Seismic Design Technical Brief No. 2, NEHRP Consultants Joint Venture, Applied Technology Council and Consortium of Universities for Research in Earthquake Engineering, National Institute of Standards and Technology, Gaithersburg, MD, NIST GCR 09-917-3.

Kaveh, A. & Mahdipour Moghanni, Roya & Javadi, Seyed Mohammad. (2022). Chaotic optimization algorithm for performance-based optimization design of composite moment frames. Engineering with Computers. 38. 1-13. 10.1007/s00366-020-01244-z.

Kottke, A. , Rathje, E. (2020). *SigmaSpectra: Ground motion selection and scaling software* [Computer software]. Version 1.1.0, released under GNU General Public License (GPL). https://doi.org/10.5281/zenodo.3694198

Lignos, D. G., and Krawinkler, H. (2010). *Deterioration modeling of steel components in support of collapse prediction of steel moment frames under earthquake loading*. Journal of Structural Engineering. https://doi.org/10.1061/(ASCE)ST.1943-541X.0000376.

Lignos, D. G., Hartloper, A. R., Elkady, A., Deierlein, G. G., and Hamburger, R. (2019). *Proposed updates to the ASCE 41 nonlinear modeling parameters for wide-flange steel columns in support of performance-based seismic engineering*. Journal of Structural Engineering, 145(9), 04019083. https://doi.org/10.1061/(ASCE)ST.1943-541X.0002376.

Pacific Earthquake Engineering Research Center (PEER). (2013). *NGA-West2 ground motion database*. Univ. of California, Berkeley, CA.

Porter, K. A. (2021). *A beginner's guide to fragility, vulnerability, and risk*. University. of Colorado Boulder, 139 pp., https://www.sparisk.com/pubs/Porter-beginners-guide.pdf

Skiadopoulos, A., Elkady, A., and Lignos, D. G. (2021). *Proposed panel zone model for seismic design of steel moment-resisting frames*. Journal of Structural Engineering, 147(4), 04021006. https://doi.org/10.1061/(ASCE)ST.1943-541X.0002945.

Vamvatsikos, D., and Cornell, C. A. (2002). "Incremental dynamic analysis." *Earthquake Engineering and Structural. Dynamics.*, 31(3), 491–514. https://doi.org/10.1002/eqe.141

Zareian, F., and Medina, R. A. (2010). "A practical method for proper modeling of structural damping in inelastic plane structural systems." *Computers and Structures*, **88**(1–2), 45–53. https://doi.org/10.1016/j.compstruc.2009.08.001.

Zhu, M. (2018). *OpenSeesPy: Python Library for the OpenSees Finite Element Framework*. Pacific Earthquake Engineering Research Center, University of California, Berkeley. Available at: https://openseespydoc.readthedocs.io/