SP3 Software Webinar Series

Introducing the New Structural Response Prediction Engine

Curt B. Haselton, PhD, PE
(and Jack Baker and the SP3 Team)

Professor of Civil Engineering @ CSU, Chico

Co-Founder and CEO @ Seismic Performance Prediction Program (SP3)

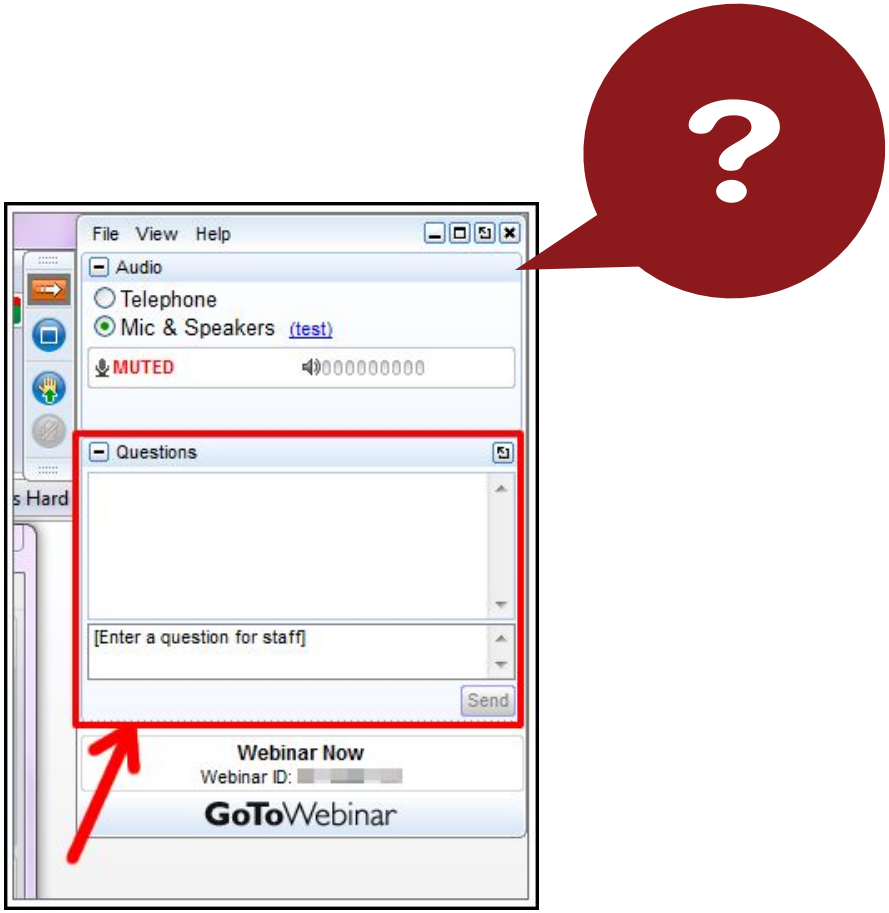
www.hbrisk.com

Housekeeping

- All phone lines are muted
- Questions are highly encourage (answered at end)
- Handouts are available – presentation slides and one-page summary of the new method
- Webinar is recorded and video will be distributed
- Please take a brief survey before signing off at end of webinar

Housekeeping

- Questions:
  - Please use questions tab and we will address as many as we can at the end.
  - For further questions, contact Dr. Haselton directly (curt@hbrisk.com) or contact the SP3 team (support@hbrisk.com).



Housekeeping

- This is the first webinar in our series, so please watch for announcements for our next three webinars!

- **Webinar Series:**
  1) The new SP3 Structural Response Prediction Engine
  2) Risk assessment of wood light-frame buildings using SP3
  3) Risk assessment of tilt-up buildings using SP3
  4) SP3: A consistent platform for building-specific seismic risk assessment for low-levels to high-levels of building input information

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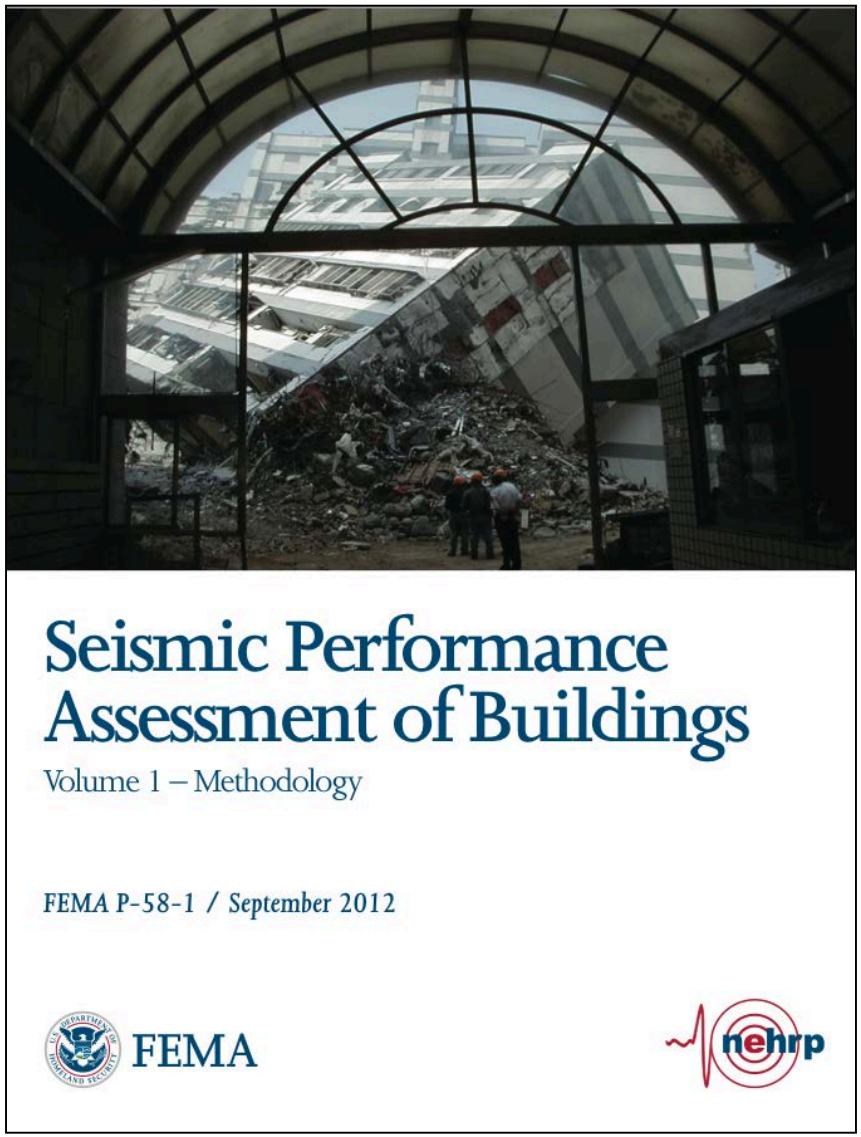
Outline for Today

- Brief overview of FEMA P-58 and the SP3 software
- The need for rapid and advanced seismic risk evaluation
- The new Structural Response Prediction Engine:
  - Overview of approach
  - Detail of what is under the hood
  - What the Engine now enables
- Current and next steps for SP3 Research & Development
- Questions

FEMA P-58 Overview

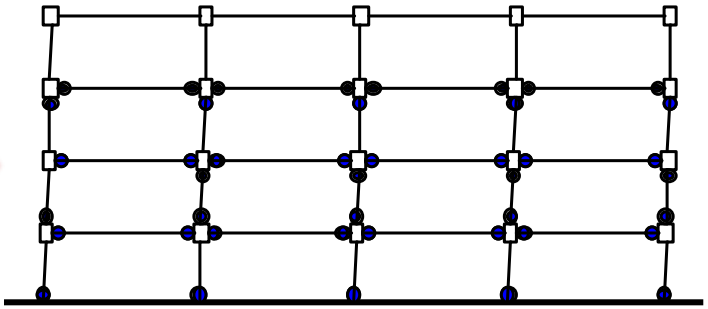
- FEMA P-58 is a probabilistic performance prediction methodology (15 years of effort to date, ~$16M invested by FEMA)
- FEMA P-58 is tailored for building-specific analysis (in contrast to most risk assessment methods that give results by building class)
- FEMA P-58 output results:
  - Repair costs
  - Repair time
  - Safety: Fatalities & injuries



FEMA P-58 Overview

SP3 uses FEMA P-58 and adds much more:

Ground Motion Hazard

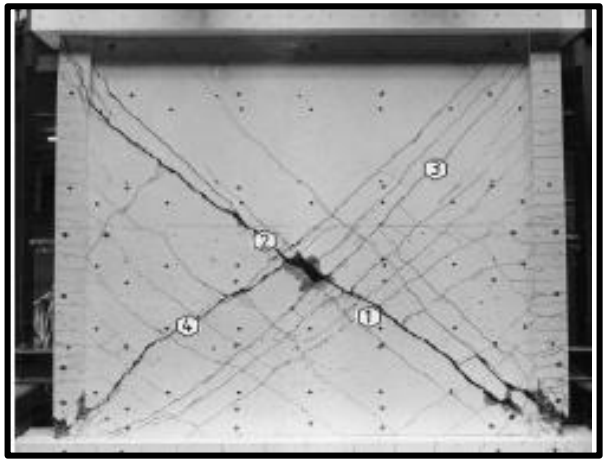


Structural Responses

Economic Loss

Casualties

Repair Time



Component Damage

SP3 Software Compliments FEMA P-58

FEMA P-58 provides the **comprehensive** and **standardized** building-specific risk assessment (with ~$16M to develop).

SP3 provides a user-friendly software to integrate all steps in a FEMA P-58 risk assessment.

The initial assessment should take a couple **hours** and **not days or weeks**.

Our Goal with SP3

- **Our Goal:**

  To enable and facilitate rapid and advanced building-specific seismic risk assessments for all buildings *(i.e. building-specific vulnerability curves)*.

- **Expected Outcomes:**

  We believe that this will (a) facilitate the design of more resilient buildings and (b) enable better risk-related decision making *(e.g. insurance risk, mortgage risk, etc.)*.

Current Uses of SP3 Software

- **Current uses of SP3:**
  - Licensed by ~80+% of the large west-coast structural engineering firms, and has been expanding from there.
  - Currently being used for:
    - Resilient design of new buildings (municipal buildings, court houses, etc.)
    - Retrofit of existing buildings
    - Assessments of special facilities (EOCs, manufacturing, museums, etc.)
    - Mortgage risk assessments [needs rapid risk methods]
    - Investment risk assessments [needs rapid risk methods]
    - Insurance risk assessments [needs rapid risk methods]

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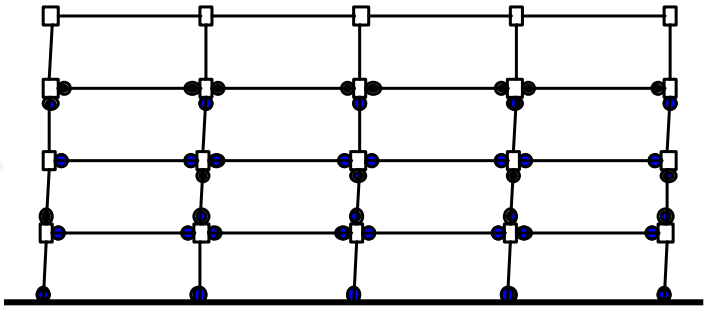
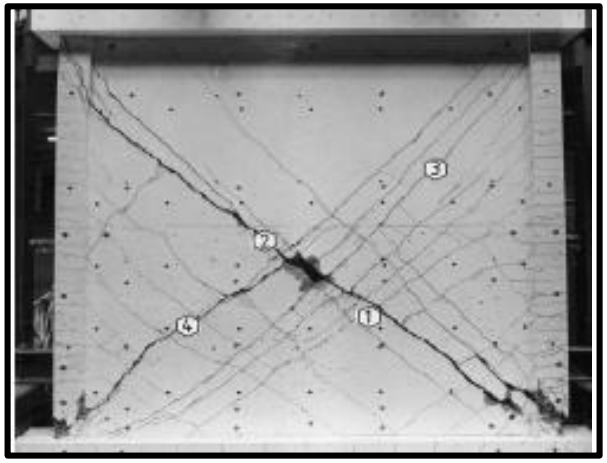
The Need for Rapid Risk Evaluations

Ground Motion Hazard



Structural Responses



Component Damage

Casualties

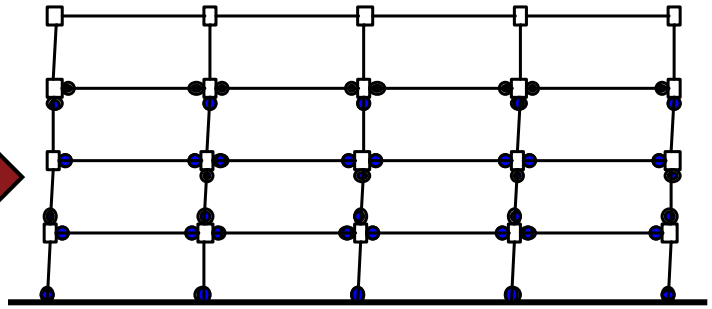
Economic Loss

Repair Time

The Need for Rapid Risk Evaluations

SP3 Structural Response Prediction ENGINE

"We do the nonlinear dynamic structural analysis for you."



Structural Responses

[and contrast to FEMA P-58 "Simplified Method"]

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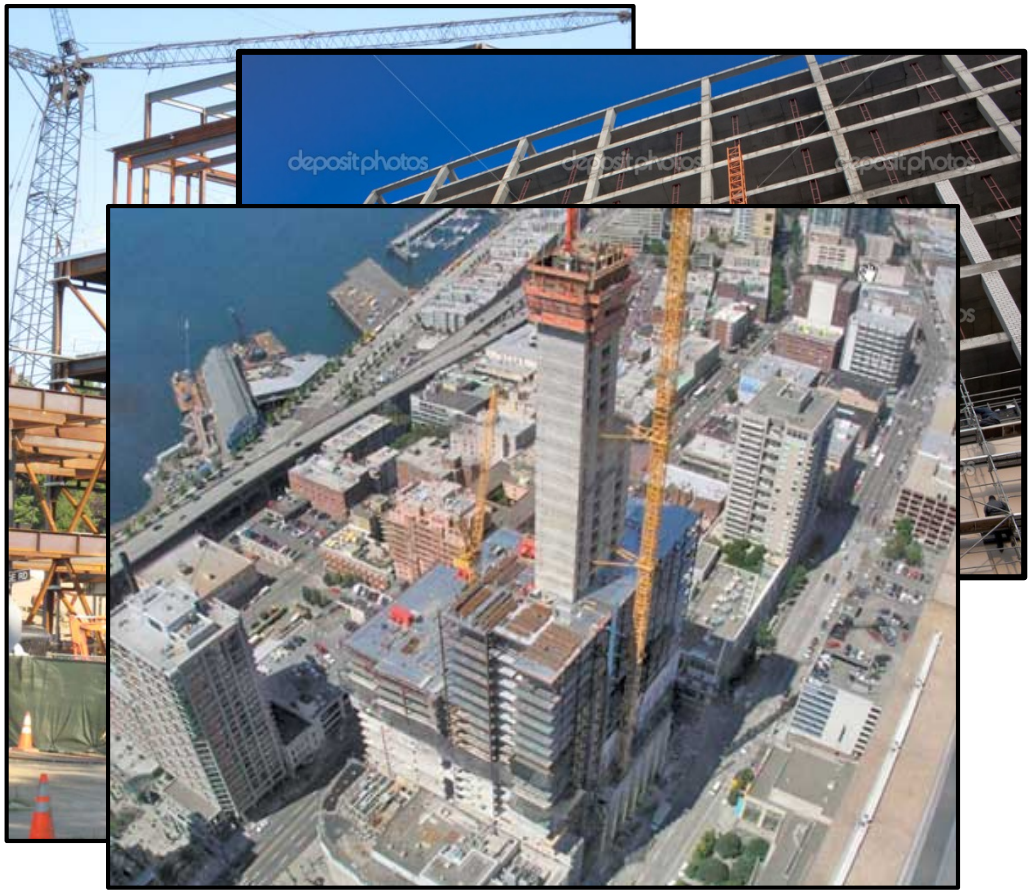
Approach to the SP3 Str. Response Prediction Engine

- We first assembled a large set of structural models and simulated nonlinear responses for many ground motion levels.



OpenSees

Approach to the SP3 Str. Response Prediction Engine

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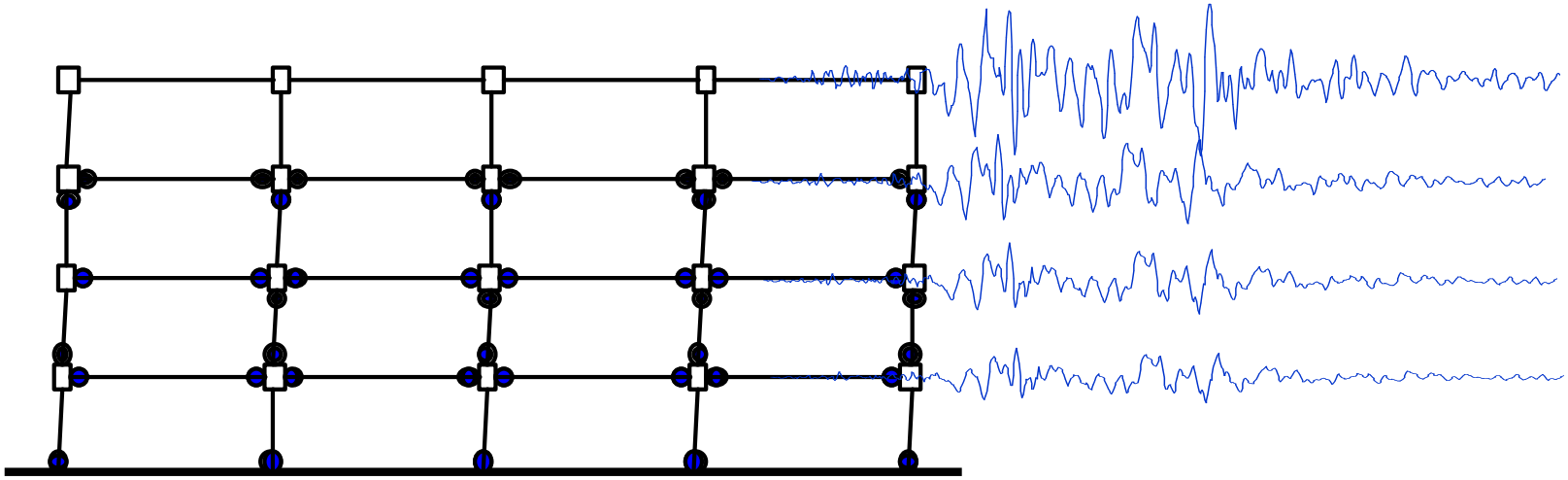

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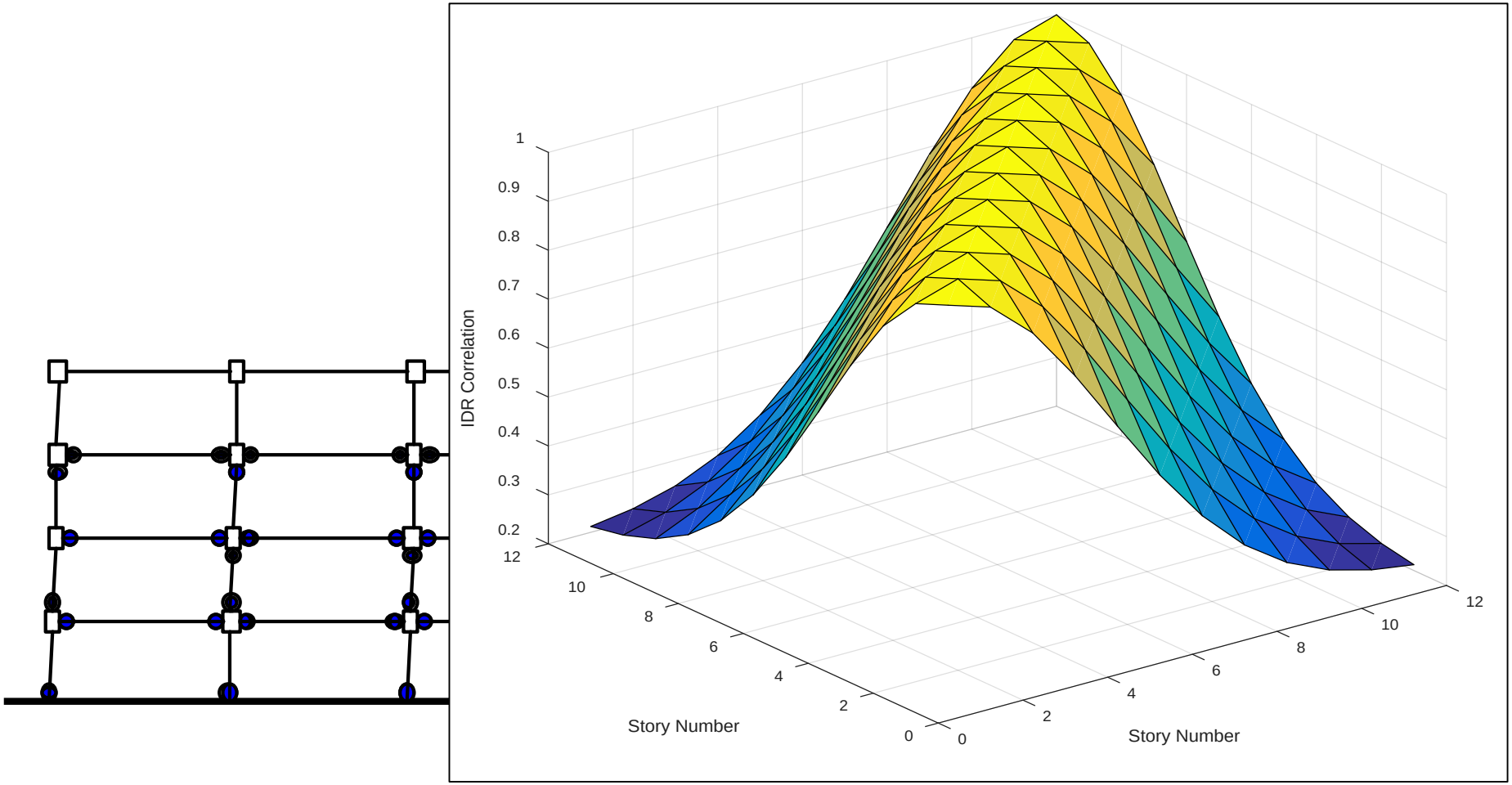

Approach to the SP3 Str. Response Prediction Engine

- We first assembled a large set of structural models and simulated nonlinear responses for many ground motion levels.

252
Nonlinear Structural Models

>4,000,000
Nonlinear Structural Responses in our Growing Database of Response-History Analyses

>475,920
Minutes of Processor Run Time to Create our Database of Structural Responses

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Approach to the SP3 Str. Response Prediction Engine

SP3 Structural Response Prediction ENGINE

"We do the nonlinear dynamic structural analysis for you."

Engineering Demand Parameters
for ~100 ground motions
(drifts and floor accelerations)

Approach to the SP3 Str. Response Prediction Engine

SP3 Structural Response Prediction ENGINE

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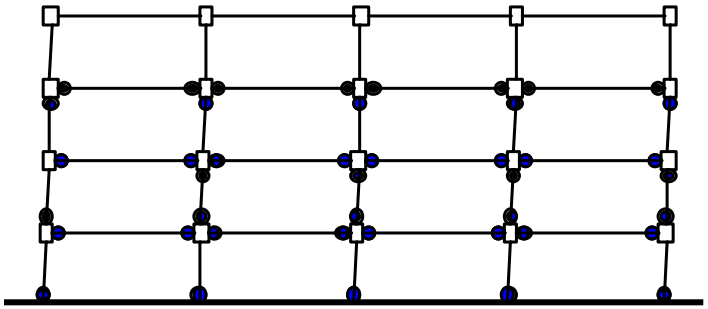


Structural Responses

Database: Structural responses from hundreds of nonlinear structural models with millions of nonlinear response-history analyses.

Structural Inputs:

- Building strength
  - T_1, T_2, and T_3
- First three mode shapes

SP3 Auto-Population ENGINE

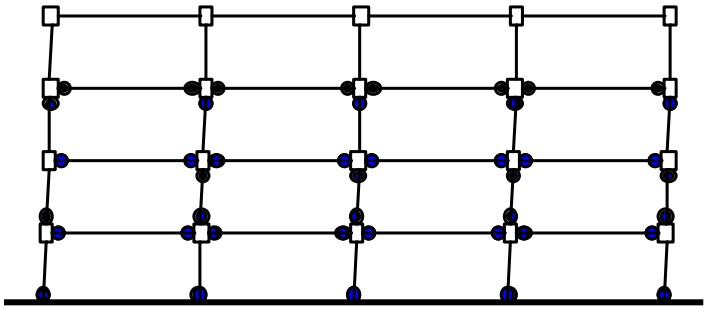
Inputs:

- Building system and height
- Building age (and/or code)
- Building location
- Other optional site/design info.

Approach to the SP3 Str. Response Prediction Engine

Inputs for New "Low Data" Option:

- Building system and height
- Building age (and/or code)
- Building location
- Other optional site/design info.



Structural Responses

Inputs for New "Intermediate Data" Option:

- Building strength
- T1, T2, and T3
- First three mode shapes

Previous "Full Data" Option:

- Create a structural model, run nonlinear response-history analyses, and input results manually.

Approach to the SP3 Str. Response Prediction Engine

Creating the SP3 Str. Response Prediction Engine

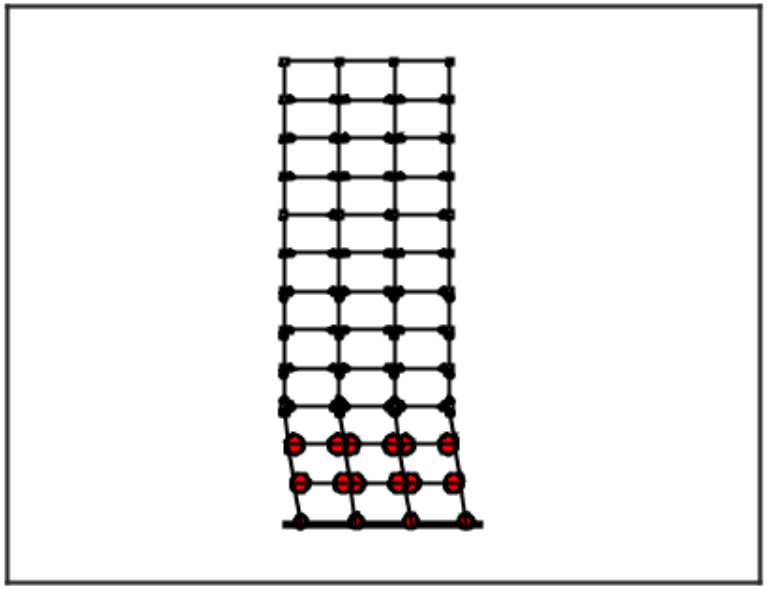
- This was an overview of how we created the new SP3 Response Engine.
- Let’s now get into more of the detail.

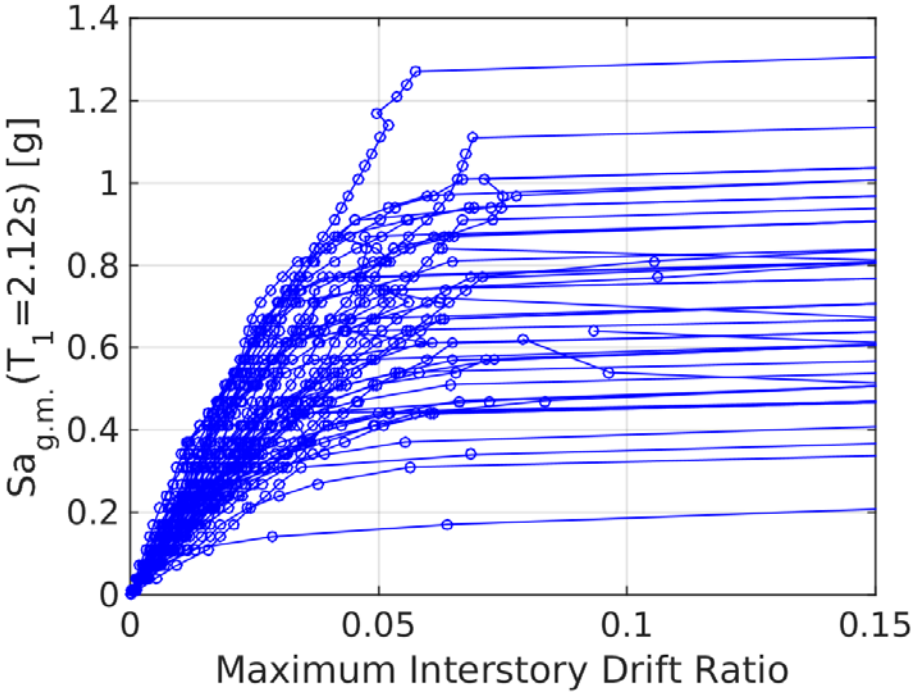
Creating the SP3 Str. Response Prediction Engine

- Example data set for a 12-story Reinforced Concrete Special Moment Frame in high-seismic California.

Creating the SP3 Str. Response Prediction Engine

- Example data set for a 12-story Reinforced Concrete Special Moment Frame in high-seismic California.





Creating the SP3 Str. Response Prediction Engine

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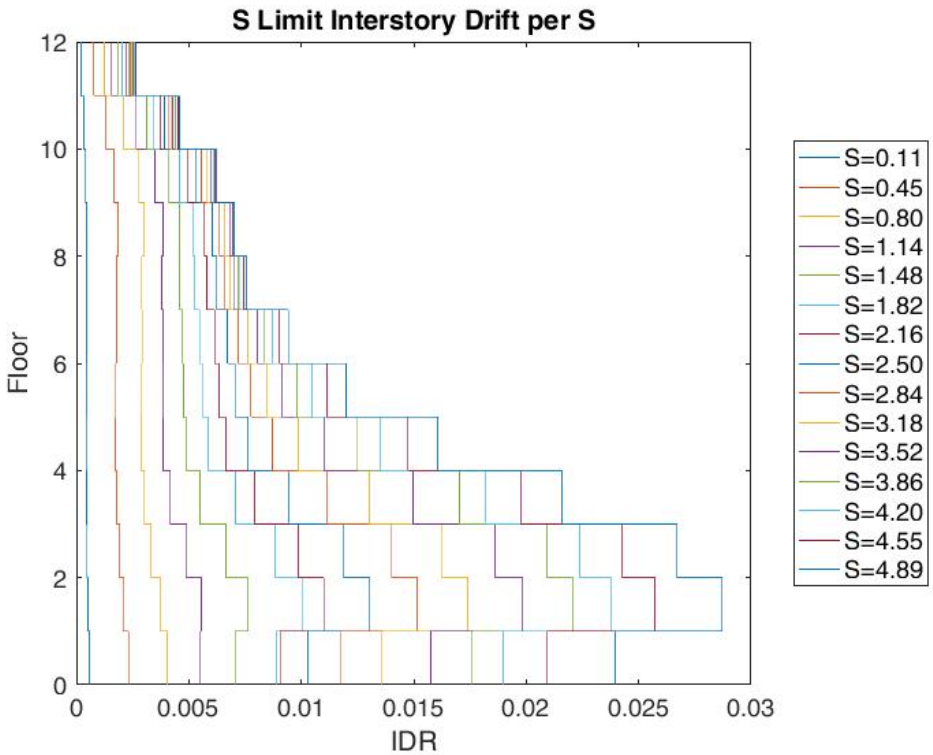
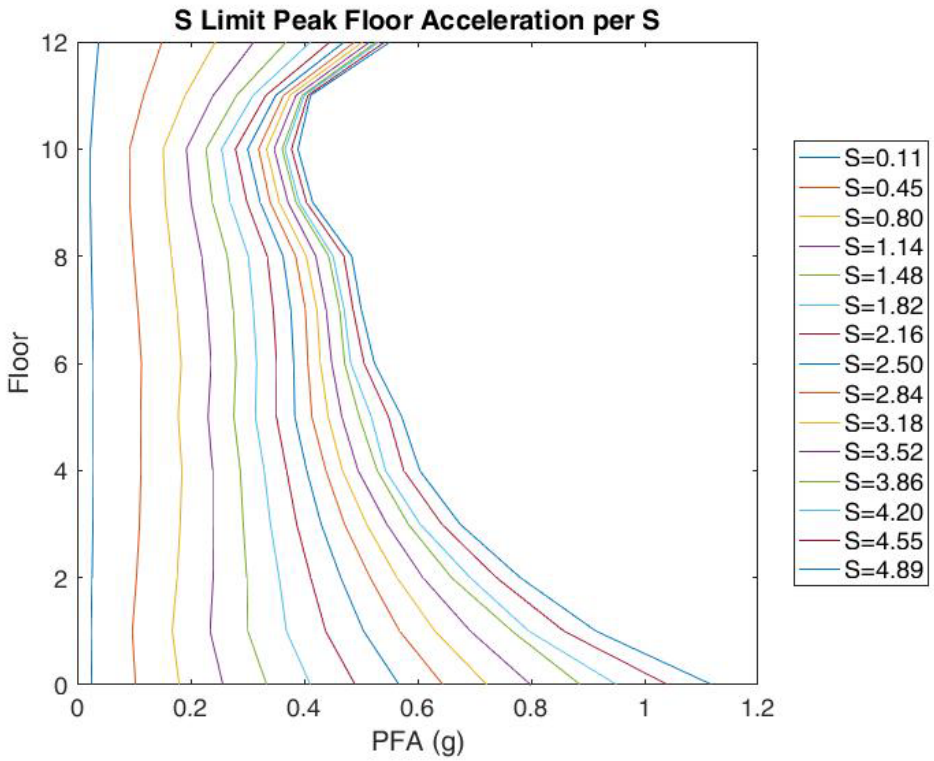
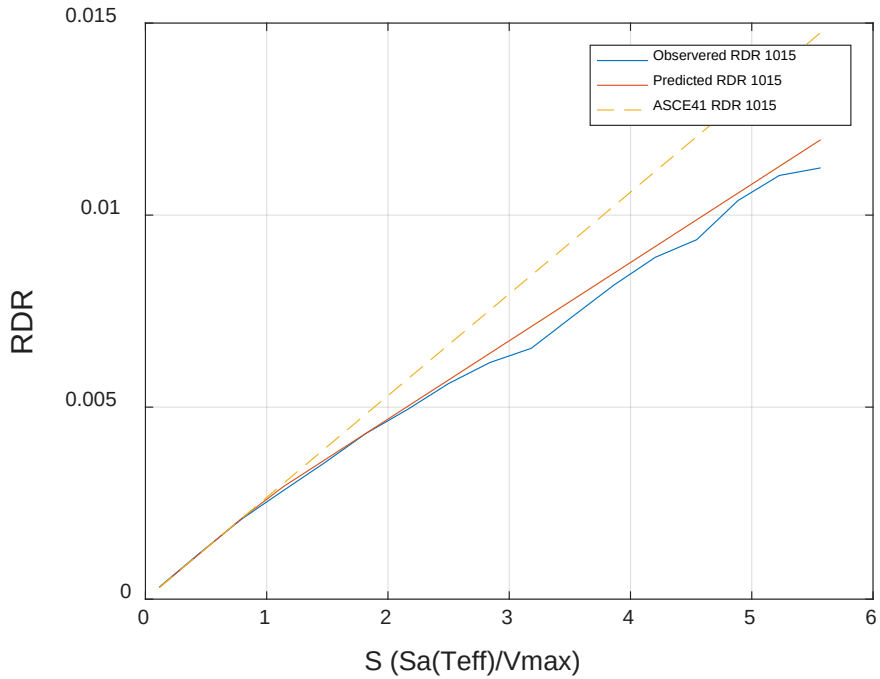




Creating the SP3 Str. Response Prediction Engine

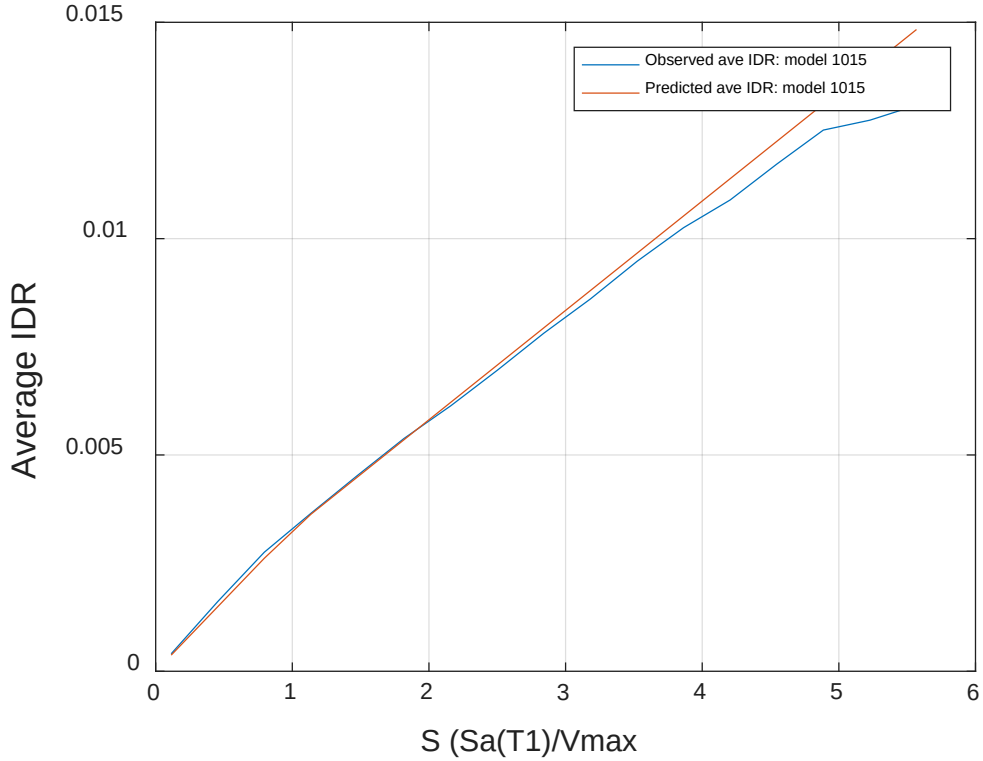
- Creating the drift prediction algorithm:
- Step 1: Use nonlinear response data set to get correct building global displacement demands.
  - Start with ASCE 41 target displacement.
  - Correct this based on the database of structural responses.

$$\delta_t = C_0 C_1 C_2 S_a \frac{{T_e}^2}{4\pi^2} g$$



Creating the SP3 Str. Response Prediction Engine

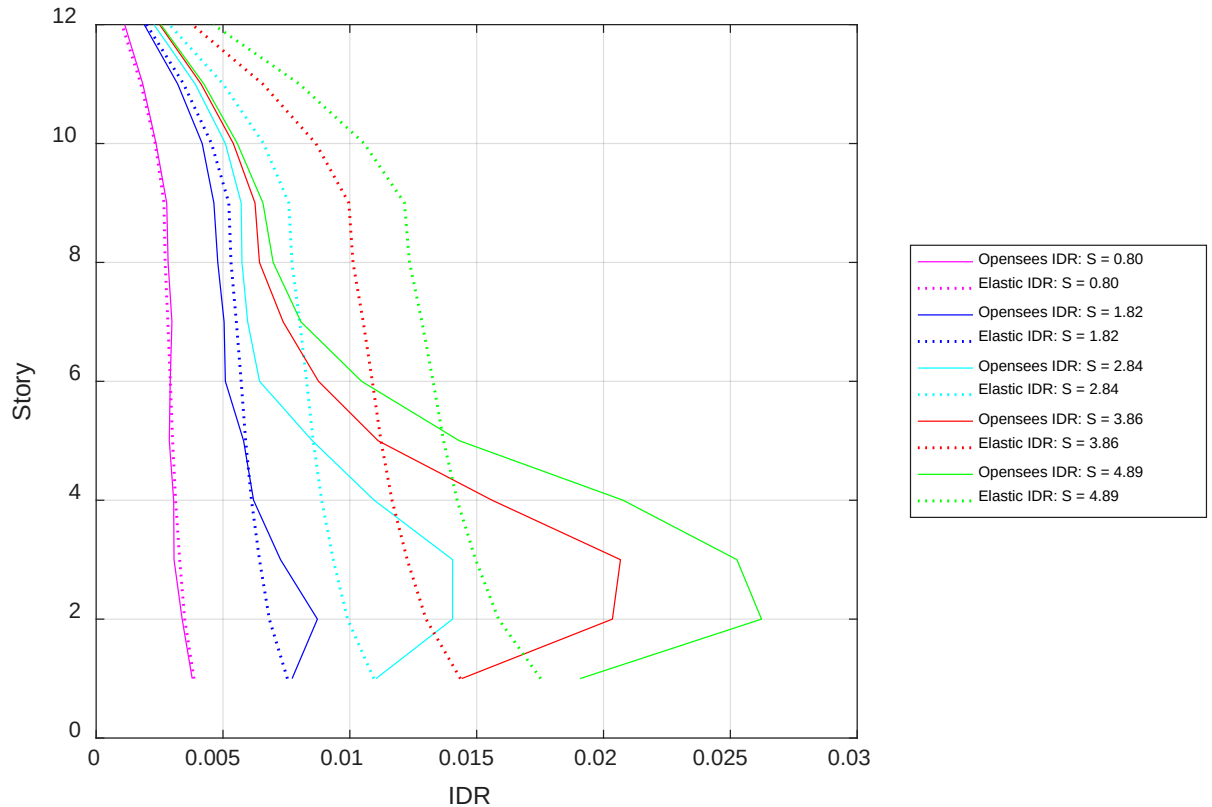
- Creating the drift prediction algorithm:
- Step 2: Since peak story drifts over height do not occur all at the same time, use the database data to get the average story drifts correct.



Creating the SP3 Str. Response Prediction Engine

- Creating the drift prediction algorithm:

- Step 3: Do a three-mode modal analysis to compute elastic story drift profiles. This is based on T_1-T_3 and φ_1-φ_3 either from an input or auto-populated based on building type and design information.



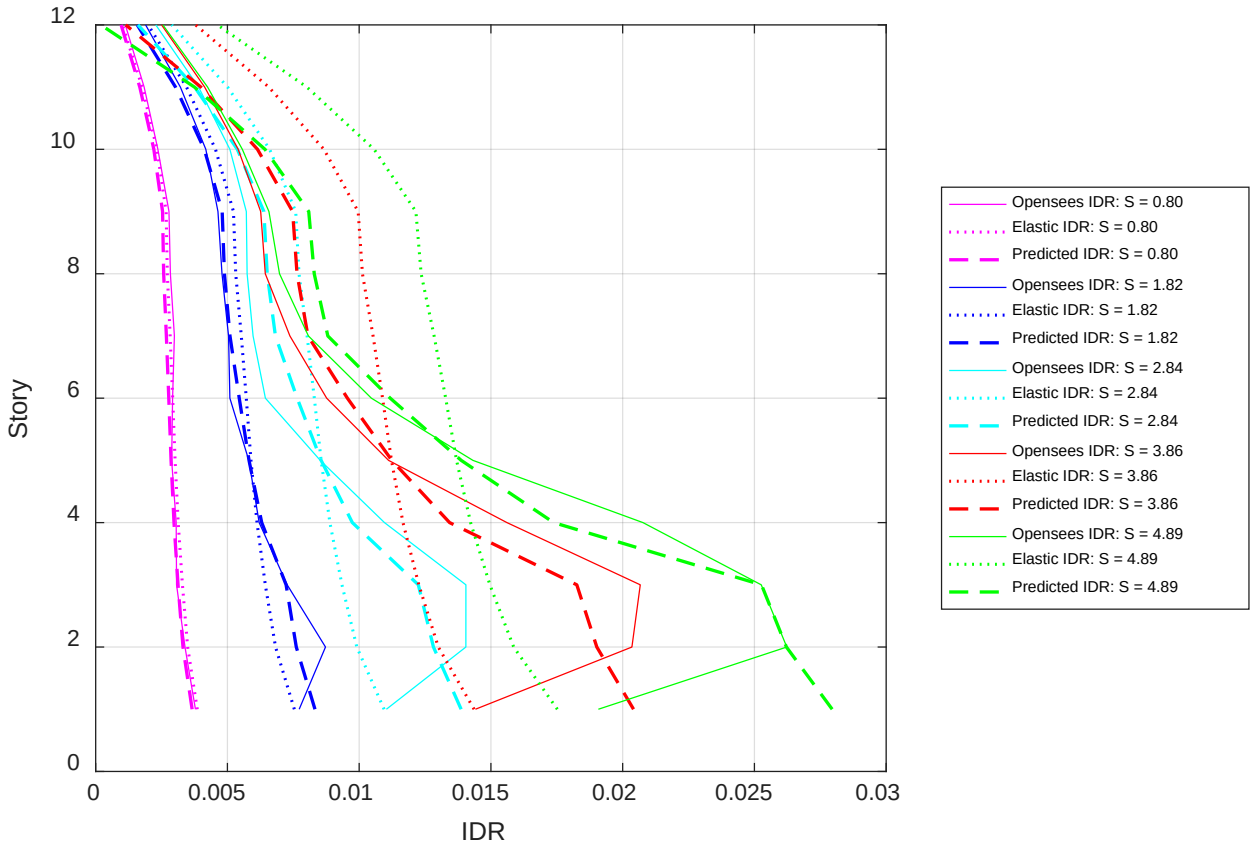
Creating the SP3 Str. Response Prediction Engine

- Creating the drift prediction algorithm:

- Step 4: Use the response database to modify the response to account for inelastic effects.
  - This includes an adjustment to the global drifts, to account for inelastic damping effects (when they occur).
  - This also handles where the drifts localize over height (which depend on structural system and design approach, e.g. strong column-weak beam).

Creating the SP3 Str. Response Prediction Engine

- Creating the drift prediction algorithm:
- Step 4: Use the response database to modify the response to account for inelastic effects.



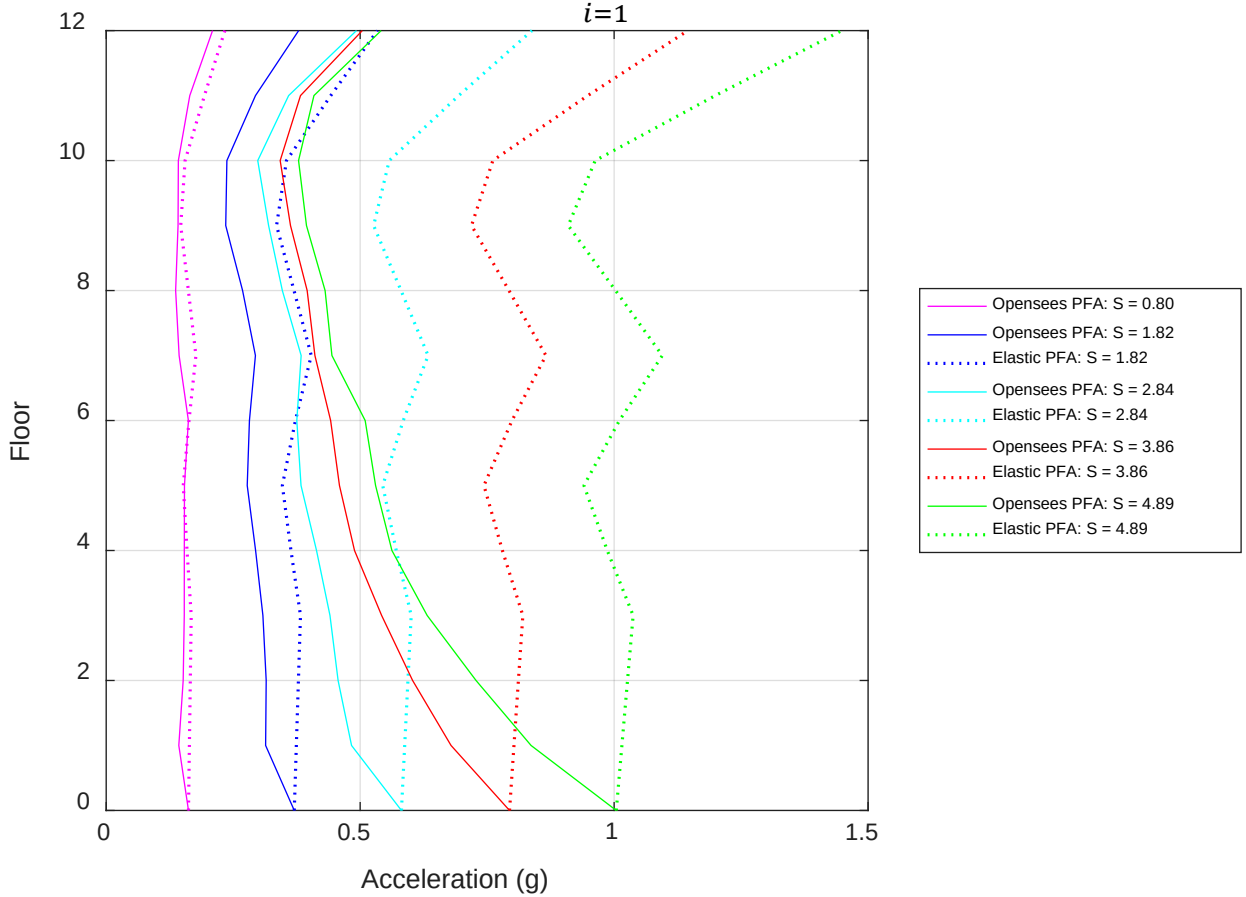
Creating the SP3 Str. Response Prediction Engine

- The drift prediction algorithm is now done!
- Now, let's look at creating the floor acceleration prediction algorithm.

Creating the SP3 Str. Response Prediction Engine

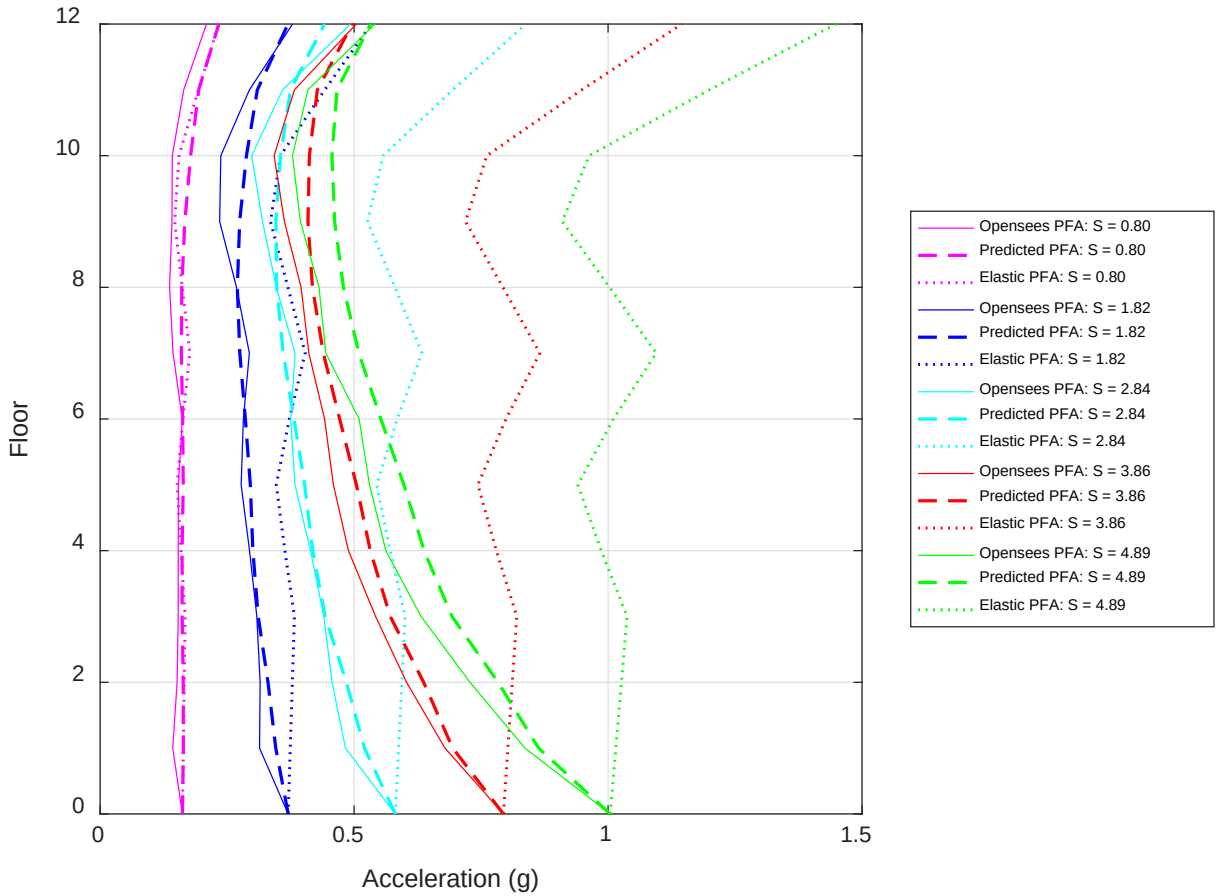
- Creating the floor acceleration prediction algorithm:
- Step 1: Do a three-mode modal analysis to estimate elastic floor accelerations.

$$PFA_n = \sum_{i=1}^{3} \Gamma_i \phi_{i,n} \ddot{u}(t)_i$$



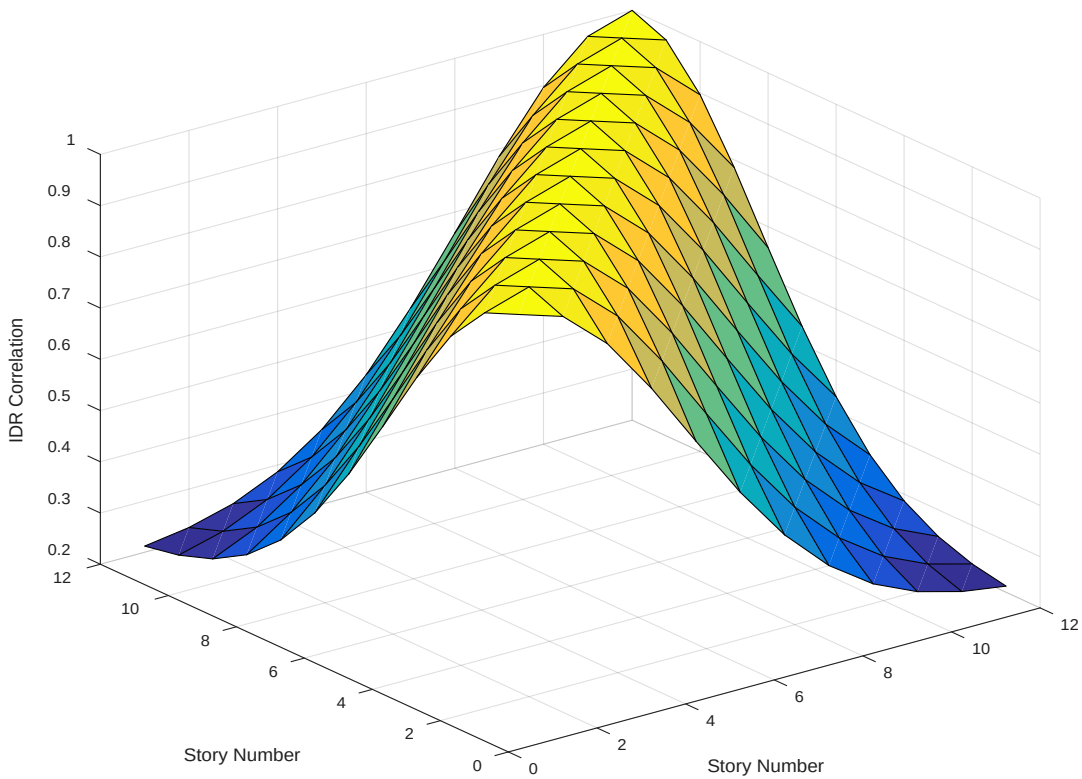
Creating the SP3 Str. Response Prediction Engine

- Creating the floor acceleration prediction algorithm:
- Step 2: Use structural response database to capture the effects of inelastic behavior.



Creating the SP3 Str. Response Prediction Engine

- Response correlations:
  - Getting these right is <u>crucial</u> to getting a meaningful estimate of variability in the final risk prediction (e.g. getting full curve to estimate things like 90th percentile of losses).



Summary of SP3 Structural Response Engine

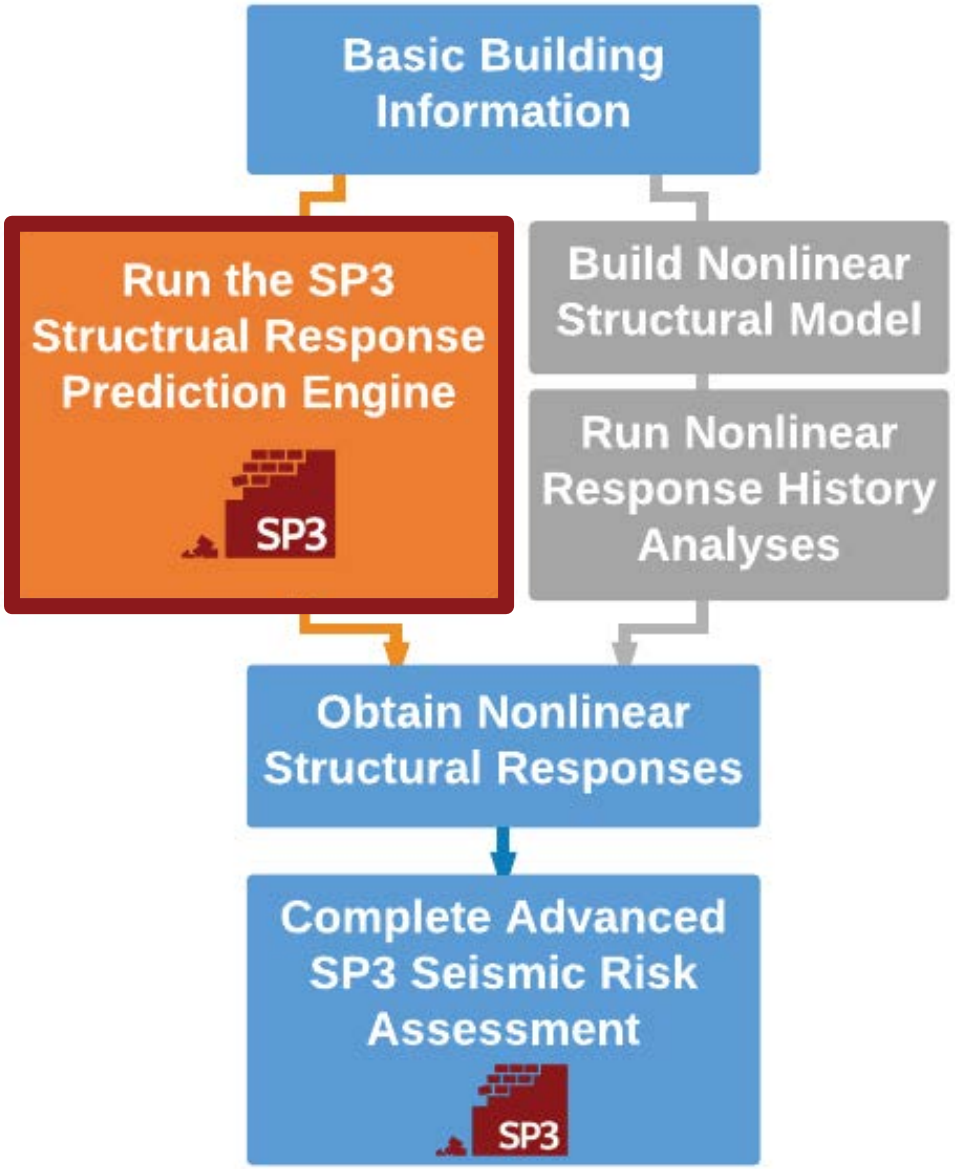
- To summarize…

Summary of SP3 Structural Response Engine

This new ENGINE enables a high-fidelity SP3 risk assessment without needing to build a nonlinear structural model.

This does not replace modeling by a structural engineer and some applications of SP3 will still include modeling, in order to reduce the uncertainty in the risk assessment (e.g. for resilient design of new buildings).

However, this opens the door to high-fidelity risk assessments for the many cases where a structural model is not feasible (e.g. initial structural design, insurance risk, mortgage risk, investment risk, etc.).



Summary of SP3 Structural Response Engine

- Current scoping limitations of SP3 Structural Response Prediction Engine:
  - Applies up to 25 stories (wood up to 5-story with up to 2-story pedestal)
  - Calibrated for both ductile and non-ductile buildings (e.g. RC SMF, OMF, and 1960's RC frames)
  - Regular buildings (and currently being extended)
  - Data set supports low levels of ground motion (elastic) to high levels (highly nonlinear); include response up to 25% collapse rate (so no meaningful limits on ductility level)
  - Response correlations are carefully tracked, so a full distribution of risk results can be reliably provided (e.g. 90% percentile).
  - Most aspects of the Engine are generic to all structural systems (e.g. modal analysis), but inelastic factors are currently based on frame data (and are currently being extended).

Next Research and Development Steps

- With substantial funding from the National Science Foundation ($980k to date), we are also continuing further development for rapid and advanced building-specific risk assessment.

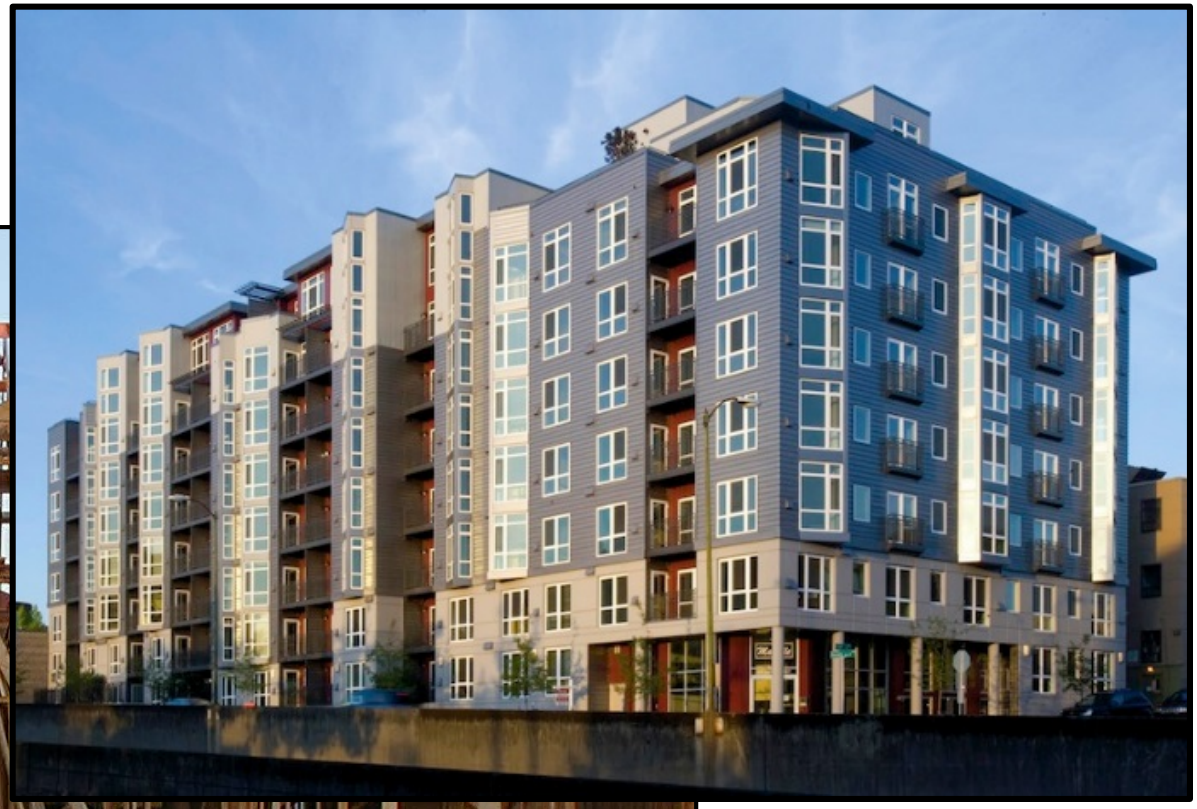
- The research focuses are:
  - ✓ Further extending and refining the Structural Response Prediction Engine.
  - ✓ Rapid assessment of wood light-frame buildings (done).
  - ✓ Rapid assessment of tilt-up buildings.

Next Research and Development Steps

- Next steps on the SP3 Response Engine:
  - Extend to taller – up to 40 stories
  - Refine inelastic factors for additional structural systems – e.g. current in-progress project looking at buckling-restrained braced frame buildings up to 40-stories
  - Extend to irregular – vertical weak story and plan torsion (structural analyses are already completed in the database)

Next Research and Development Steps

- Wood light frame (covers single- and multi-family, up to 5-stories of wood and 1-2 stories of podium) [method is complete]



Next Research and Development Steps

- Tilt-up buildings (rigid-wall flexible diaphragm) – inclusive of all building era's, focus on tilt-up panels with wood diaphragms (i.e. buildings is western half of the U.S.)

Closing and Questions

- Thank you for your time.
- Our goal is to support adoption of resilience-based design and risk assessment, and we welcome feedback and suggestions.

- Time for questions!

Curt Haselton: *curt@hbrisk.com, Direct: (530) 514-8980*

Jack Baker: *jack@hbrisk.com*

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Upcoming Webinars in this Series

- Please watch for announcements for our next three webinars!

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  1) The new SP3 Structural Response Prediction Engine
  2) Risk assessment of wood light-frame buildings using SP3
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Closing and Questions

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