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)

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- 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
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).
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
SP3 uses FEMA P-58 and adds much more:

- **Ground Motion Hazard**
- **Structural Responses**
- **Economic Loss**
- **Casualties**
- **Repair Time**
- **Component Damage**

FEMA P-58 Overview
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:
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]
Our Goal with SP3

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The Need for Rapid Risk Evaluations

Ground Motion Hazard

Structural Responses

Economic Loss

Casualties

Repair Time

Component Damage
The Need for Rapid Risk Evaluations

SP3 Structural Response Prediction ENGINE

“We do the nonlinear dynamic structural analysis for you.”

[and contrast to FEMA P-58 “Simplified Method”]
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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
- We first assembled a large set of structural models and simulated nonlinear responses for many ground motion levels.
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- 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
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**

“We do the nonlinear dynamic structural analysis for you.”

**Structural Inputs:**
- Building strength
- $T_1$, $T_2$, and $T_3$
- First three mode shapes

**SP3 Auto-Population ENGINE**

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

**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.

**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

1. Basic Building Information
2. Run the SP3 Structural Response Prediction Engine
3. Build Nonlinear Structural Model
4. Run Nonlinear Response History Analyses
5. Obtain Nonlinear Structural Responses
6. Complete Advanced SP3 Seismic Risk Assessment
This was an overview of how we created the new SP3 Response Engine.

Let’s now get into more of the detail.
Example data set for a 12-story Reinforced Concrete Special Moment Frame in high-seismic California.
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Example data set for a 12-story Reinforced Concrete Special Moment Frame in high-seismic California.
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.

\[
\delta_t = C_0 C_1 C_2 S_a \frac{T_e^2}{4\pi^2} \cdot g
\]
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 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 $\varphi_1-\varphi_3$ either from an input or auto-populated based on building type and design information.
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 drift prediction algorithm:

Step 4: Use the response database to modify the response to account for inelastic effects.
The drift prediction algorithm is now done!

Now, let’s look at creating the floor acceleration prediction algorithm.
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 floor acceleration prediction algorithm:

- Step 2: Use structural response database to capture the effects of inelastic behavior.
Response correlations:

- Getting these right is crucial 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).
To summarize...
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.).
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).
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)
- 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!

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