The SP3
Structural Response Prediction Engine

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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 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
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”]
We first assembled a large set of structural models and simulated nonlinear responses for many ground motion levels.
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Approach to the SP3 Str. Response Prediction Engine

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

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.

Previous “Full Data” Option:
- Create a structural model, run nonlinear response-history analyses, and input results manually.

Inputs for New “Intermediate Data” Option:
- Building strength
- T1, T2, and T3
- First three mode shapes
Approach to the SP3 Str. Response Prediction Engine

1. Basic Building Information
   - Run the SP3 Structural Response Prediction Engine
     - Build Nonlinear Structural Model
     - Run Nonlinear Response History Analyses
   - Obtain Nonlinear Structural Responses
   - 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.

\[ \delta_t = C_0 C_1 C_2 S_a \frac{T_e^2}{4\pi^2} g \]
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 90\textsuperscript{th} percentile of losses).
- 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.).
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).
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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