Case studies to characterize the seismic demands for high-rise buildings

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Acknowledgements:
Graham Powell, CSI, John Wallace, nees@berkeley laboratory, Brian Morgen, Nico Luco, Jack Baker and Jennie Watson-Lamprey
What’s different about these buildings?

- They are tall.
- Has many higher modes.
- Long mode periods (~10 sec).
- High-performance materials and innovative framing systems that does not satisfy code prescriptive limits.
- Requires special seismic review, including site specific PSHA.
Objectives

- Develop realistic computer models for actual tall buildings being constructed or already constructed.
- Conduct nonlinear dynamic analyses on 100s of ground motions selected from various $M$, $R$, $..$ bins.
- Characterize key building responses.
- Develop statistical models for these critical building responses.
- Develop guidelines for seismic design of high-rise buildings.
Prototype models

- 22-story concrete moment frame.
- 30-story space concrete moment frame with out-trigger trusses.
- 62-story concrete core shear wall with out-trigger trusses.
- 48-story concrete core shear wall.
48-story concrete core shear wall – Perform3D

cement fiber shear wall with coupling beams
Nonlinear dynamic analyses

- 3D bi-directional shaking.

Ground motion are selected based on:

- Database: PEER NGA database.
- Magnitude (Mw): > 6.5.
- Distance (R): 10 km (0 - 20 km).
- Useable periods: > 8 sec.
- Scaling factors: 1, 2 and 4.
- Synthetic ground motions: not yet implemented.

Characterize building responses.

- Such as inter-story drift, floor acceleration, story shear, story moment, plastic hinge rotation and demand in the gravity columns.
Preliminary results – M7, 10 km
Preliminary results – M7, 10 km
Variation in the structural responses
Variation in the structural responses
Effects of the scaling factor

Mean of maximum story drifts $X$ [m]

Floor number [-]

SF = 1
SF = 2
SF = 4
Effects of the scaling factor

- SF = 1
- SF = 2
- SF = 4
Roof drift ratio vs. spectra acceleration

Maximum roof drift X [%] vs. SaX(T1) [g] vs. SaX(T2) [g]
Base shear vs. spectra acceleration

![Graph showing base shear vs. spectra acceleration for different values of SaX(T1) and SaX(T2).]
Probabilistic model of EDP responses

- How can we use these findings towards performance-based design for high-rise buildings?
  - What is the annual rate (probability) that the roof drift ratio will exceed 1%?
  - What is the median roof drift ratio? If I am designing the structure for a life time of 75 years?

PEER PBEE methodology.

\[ P(EDP > edp) = \int P(EDP > edp | Sa)x|d\frac{\partial}{\partial Sa} dSa \]
Probabilistic model of EDP responses

Log(SaX(T1))

EDP = f(Sa)

P(EDP|Sa_j)
P(EDP|Sa_i)
P(EDP|Sa_k)
P(EDP|Sa_l)
Uniform hazard spectra

\[ S_a[g] = \frac{1}{RT} \]

RT = 72 years
RT = 475 years
RT = 975 years

\[(EDP > edp) = \int P(EDP|Sa)x|d(Sa)/dSa|dSa\]
Probabilistic model of EDP responses

Maximum roof drift ratio [%]

Annual rate of exceedance

\( P(EDP > \text{edp}) = 1 - (1 - \frac{1}{T})^{yr} \)

Annual rate of exceedance \( \sim = 1e-4 \)

1% roof drift ratio \( \sim = 4.2 \text{ ft} \)

Probability of exceedance for SF area with \( T = 3.9 \text{ sec} \)
Probabilistic model of EDP responses

$P(EDP > \text{edp})$ – roof drift ratio

$\text{edp} - \text{Maximum roof drift ratio} [\%]$
Building code GM scaling procedure

![Graph showing Sa vs Periods for various codes.](image)
Building code GM scaling procedure
Building code GM scaling procedure

- We have selected 24 pairs of GMs that has reasonable spectra shape (compare to the code design spectra).

- Separate the ground motions into 2 bins that represent 2 range of magnitudes.
  - Bin 1: 6.5 Mw – 7.25 Mw. (12 pairs of GMs)
  - Bin 2: > 7.25 Mw. (12 pairs of GMs)

- Following the code procedure, there is a total of 792 distinct combinations to select 7 pairs of ground motions (out of 12 pairs).
Building code GM scaling procedure
Building code GM scaling procedure
Summary

- Tall buildings has many higher mode effects.
- The structural responses are very sensitive to the ground motions.
- There is a large variation in the structural responses, if the ground motions are selected from a M, R, etc bin.

Correlation between EDP and spectral demand

- Roof drift ratio correlated more to $\text{Sa}(T_1)$
- Base shear correlated more to $\text{Sa}(T_2)$.
Summary (cont.)

Shown a simple probabilistic model to estimate EDP responses. More robust probabilistic models will be presented next time.

We are currently studying:

- Effect of gravity framing systems.
- Effect of spectrum matched motions.
- Effect of selecting GM based on CMS.
- Effect of synthetic ground motions.
Questions and suggestions?

Thank you for your attention!

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