Effect of Ground Motion Duration on Structural Collapse Risk

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Background and Motivation

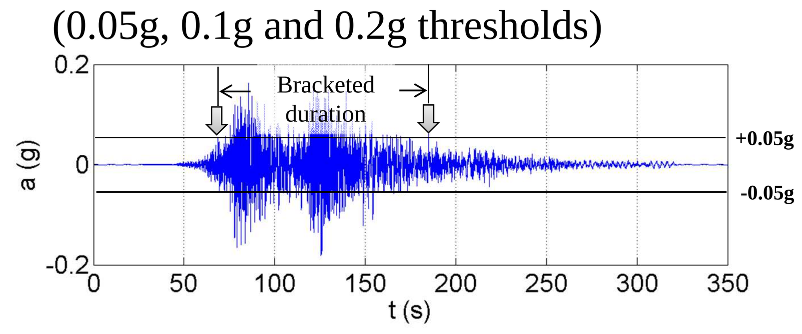
- Although ground motion duration is widely believed to be important in structural performance assessment, results from prior research have been mixed and inconclusive
- The numerical models used in these studies did not capture in-cycle and cyclic deterioration of strength and stiffness, and the effect of duration on collapse capacity has not been previously studied
- Current design provisions, performance assessment studies and cyclic loading protocols do not explicitly consider ground motion duration
- Recent large magnitude events like the 2008 Wenchuan, 2010 Chile and 2011 Tohoku earthquakes reinforce the importance of duration while providing useful new data

Objectives

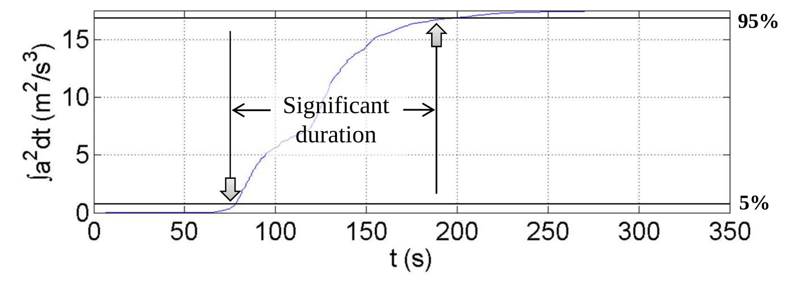
- To assess the effects of ground motion duration on structural performance and collapse capacity using realistic models that incorporate in-cycle and cyclic deterioration
- To determine which duration metric is best suited for use within the PBEE framework
- To create a benchmark long duration record set that can be used in performance assessment studies
- To identify types of structures, regions and situations where ground motion duration is expected to be important
- To evaluate and propose how to incorporate the effects of duration into the PBEE framework (in hazard characterization and ground motion selection), design codes and cyclic loading protocols

Analysis of Ground Motion Duration Metrics

Bracketed duration
(0.05g, 0.1g and 0.2g thresholds)



Significant duration
(5-95%, 5-75% and 2.5-97.5% ranges)



Arias Intensity

$$AI = \frac{\pi}{2g}\int_0^{t_{max}} a(t)^2 dt$$

Cumulative Absolute Velocity

$$CAV = \int_0^{t_{max}} |a(t)|\, dt$$

$$I_D = \frac{\int_0^{t_{max}} a(t)^2 dt}{PGA \times PGV}$$

Desired properties	Bracketed duration	Significant duration	Arias Intensity	CAV	I_D
Not strongly correlated to common intensity measures	✓	✓	×	×	✓
Unaffected by scaling	×	✓	×	×	✓
Does not bias spectral shape	✓	✓	✓	✓	×

5-95% Significant duration (t_{5-95}) also found to best capture the expected decreasing trend in collapse capacity with duration in the structures analyzed and thus identified as most suitable duration metric

Long duration record set

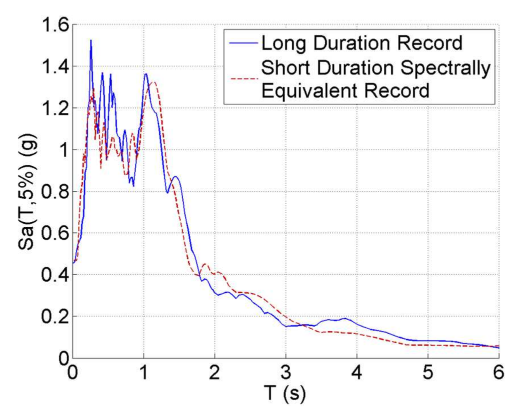
~4200 records obtained from the following events

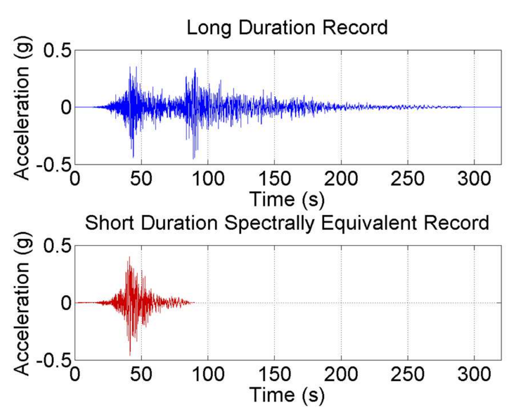
1974 Lima, Peru	2004 Niigata, Japan
1979 Imperial Valley, USA	2007 Chuetsu, Japan
1985 Valparaiso, Chile	2008 Iwate, Japan
1985 Michoacan, Mexico	2008 Wenchuan, China
1995 Kobe, Japan	2010 Maule, Chile
1999 Chi-Chi, Taiwan	2010 El Mayor Cucapah, USA
2003 Hokkaido, Japan	2011 Tohoku, Japan

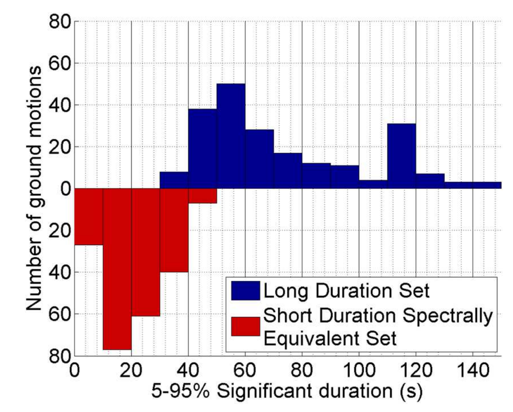
→ Screened out records with mean PGA < 0.1g, mean PGV < 10cm/s, and t_{5-95} < 45s. Maximum of 25 records retained from each event

→ 106 long duration records

Spectrally equivalent short duration record set

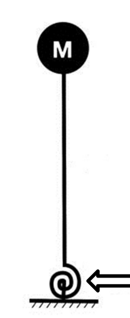






For every long duration record, a corresponding short duration record with similar spectral shape was chosen, to serve as a control for the effect of spectral shape

Concrete Bridge Pier Model



Concrete column tested by PEER and NEES at UC San Diego

Modeled as an SDOF system

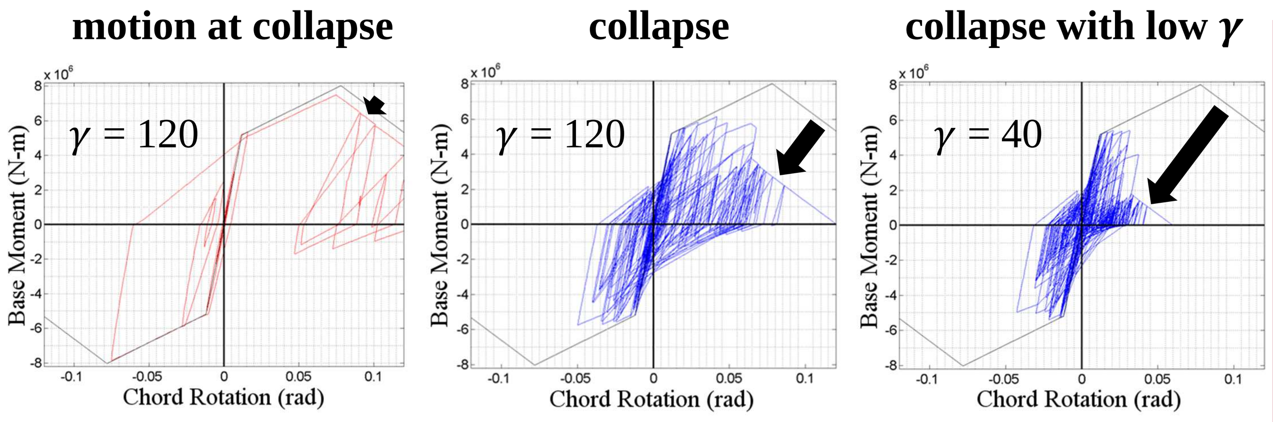
Rotational Spring
Modified Ibarra-Medina-Krawinkler peak-oriented model with in-cycle and cyclic deterioration

Initial hysteretic energy dissipation capacity $E_t = \gamma M_y \theta_y$

Deterioration governed by dissipated hysteretic energy as

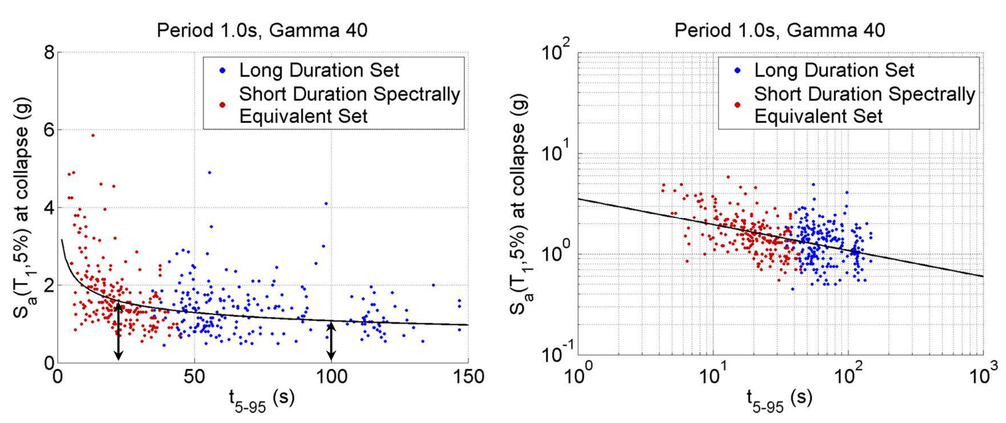
$$\beta_i = \left(\frac{E_i}{E_t - \sum_{j=1}^{i} E_j}\right)^c \longrightarrow F_i = (1-\beta_i)F_{i-1}$$

Typical short duration ground motion at collapse | **Typical long duration ground motion at collapse** | **Same long duration ground motion at collapse with low γ**



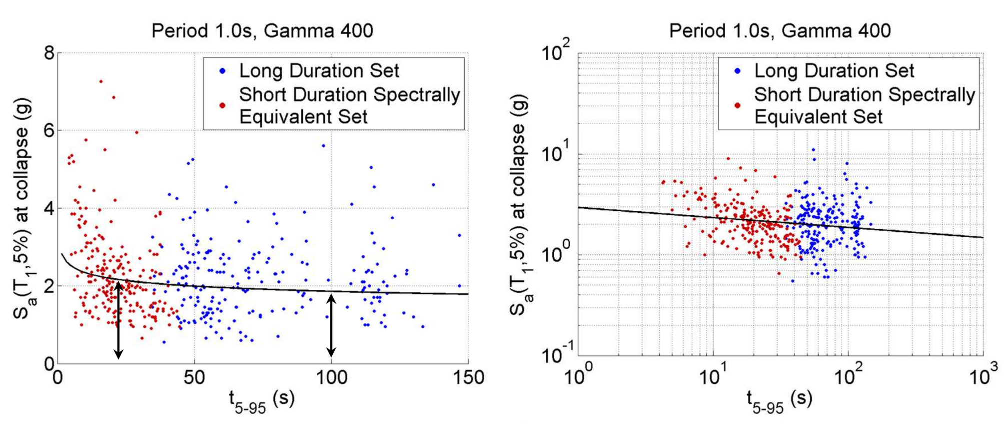
Value of γ expected to control effect of duration on collapse capacity
From calibration to test data, $T = 1.1s$, $\gamma = 120$
Analysis repeated for different periods and different values of γ

$\gamma = 40$



~35% decrease in predicted collapse capacity if t_{5-95} increased from 20s to 100s

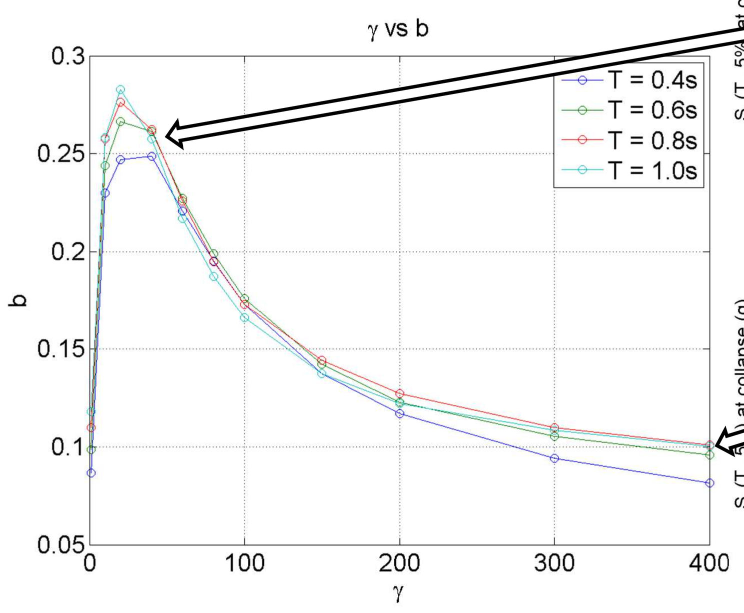
$\gamma = 400$

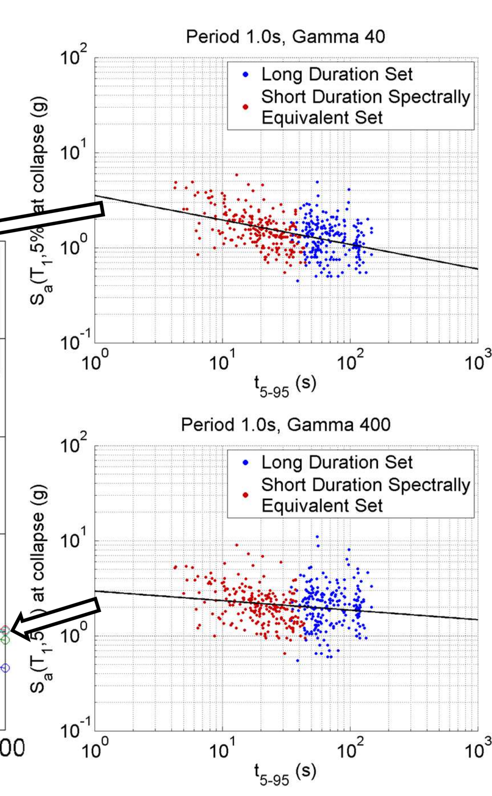


~15% decrease in predicted collapse capacity if t_{5-95} increased from 20s to 100s

$$\ln(S_a) = \ln(a) - b\,\ln(t_{5-95})$$

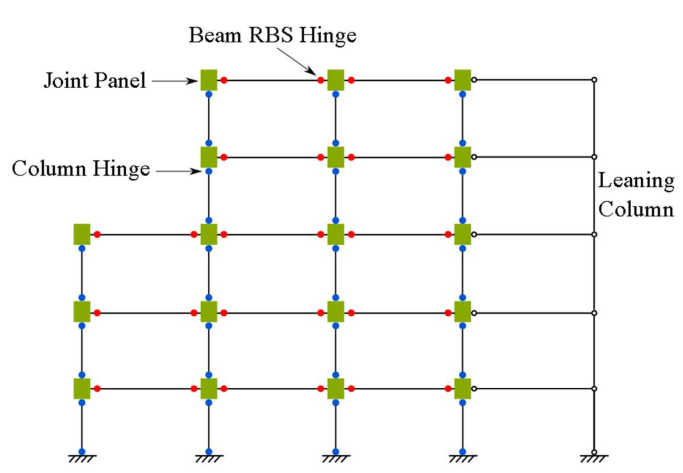
$$S_a = a\, t_{5-95}{}^{-b}$$

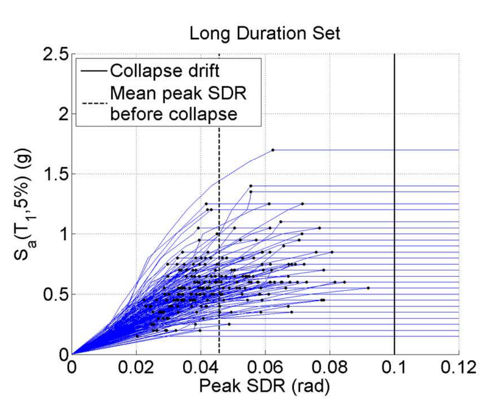


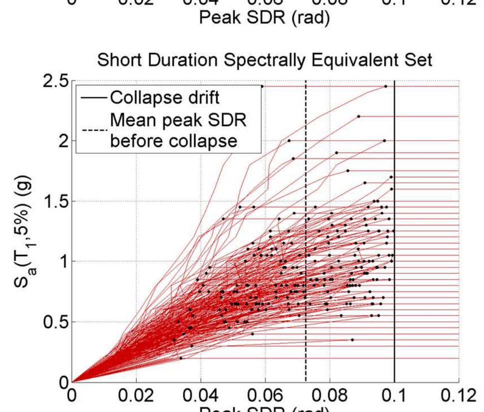


Slope b decreases with γ, but is unaffected by T as a consequence of the careful matching of response spectra of the two sets

5-Story Steel Special Moment Frame Model

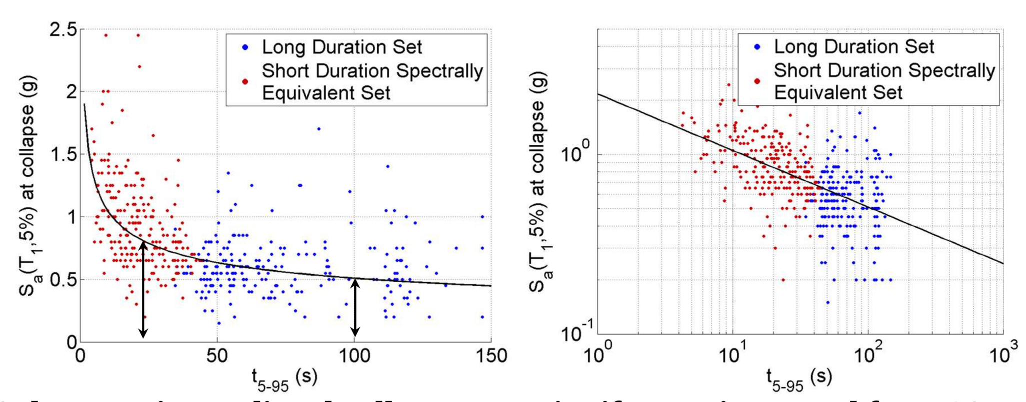




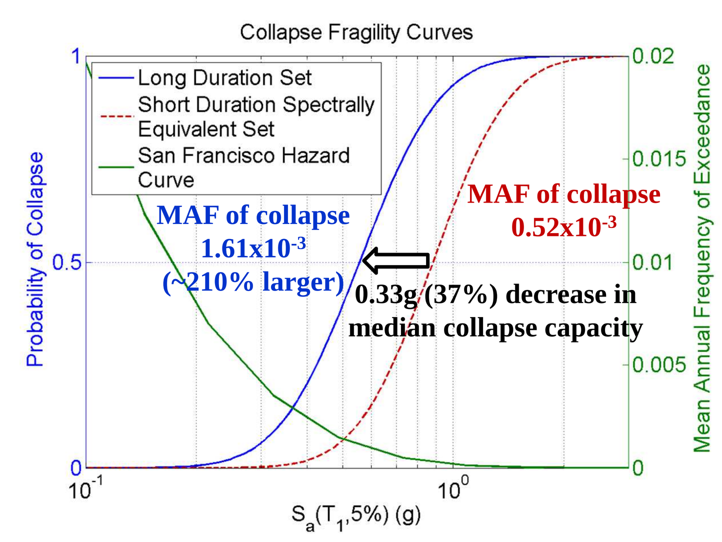


Short duration records on average reach a peak SDR of 7.3% before collapse, while long duration records reach a peak SDR of only 4.6%

Suggests that long duration shaking hastens collapse by ratcheting



~40% decrease in predicted collapse capacity if t_{5-95} increased from 20s to 100s



Even a small decrease in median collapse capacity results in a large increase in the computed MAF of collapse

Summary of Findings

- Ground motion duration is found to have a significant effect on the estimated median collapse capacities of the structures analyzed

  The decrease in estimated median collapse capacity if 100s long ground motions are used instead of 20s long ground motions was ~35% for the concrete column and ~40% for the steel moment frame
- The use of realistic (deteriorating) structural models and careful ground motion selection allowed for rigorous assessment of duration effects
- It is recommended that selected ground motions have durations consistent with those expected at the site at each hazard level
- 5-95% Significant duration is identified as the most effective duration metric

Acknowledgements

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