Effect of Long Duration Ground Motions on Structural Performance

PEER Transportation Systems Research Program

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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. Also, 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 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

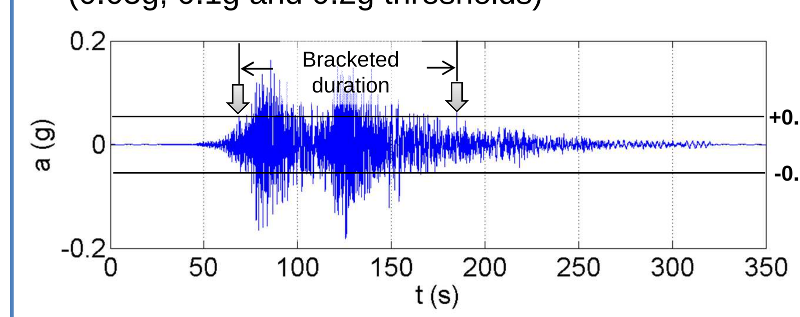
To create a benchmark long duration record set that can be used in performance assessment studies

To identify types of structures, regions and situations where ground motion duration is expected to be important

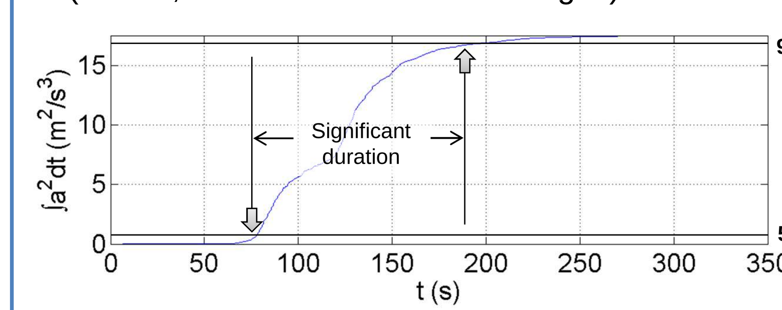
To evaluate and propose how to incorporate the effects of duration into the PBEE framework (in hazard characterization and ground motion selection), design codes and cyclic loading protocols

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

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

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

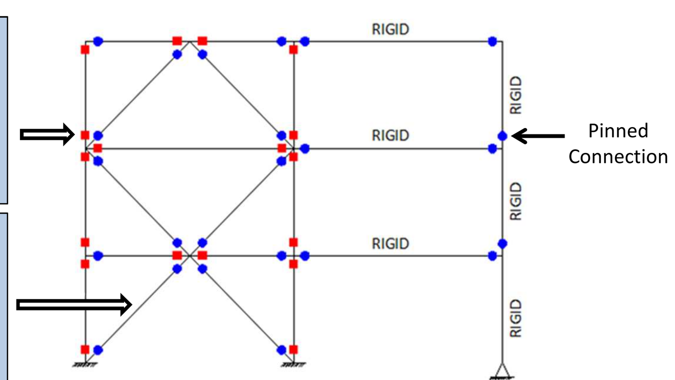
Desired properties	Bracketed duration	Significant duration	Arias Intensity	CAV	I_D
Uncorrelated to common IMs like PGA and Sa(1s)	✓	✓	×	×	✓
Unaffected by scaling	×	✓	×	×	✓
Does not bias spectral shape	✓	✓	✓	✓	×

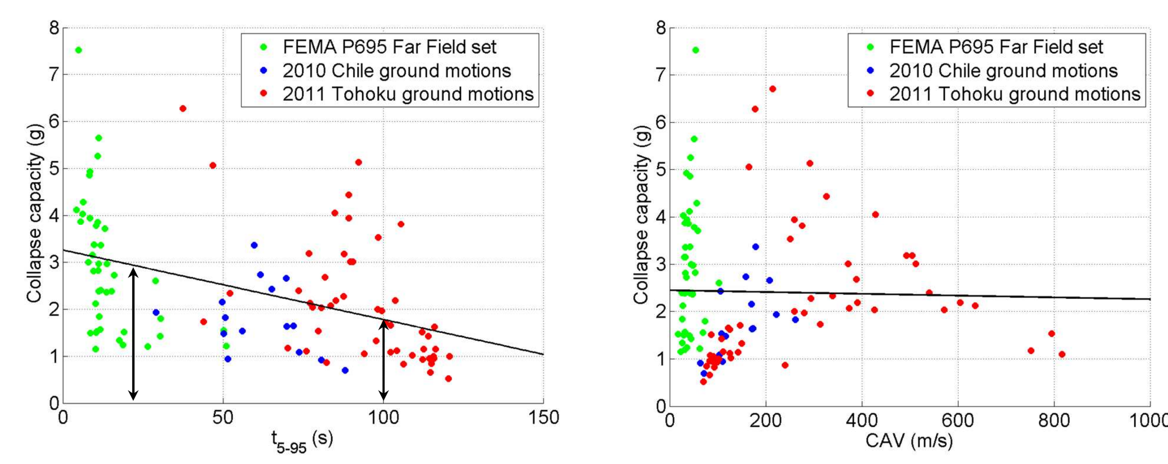
5-95% Significant duration (t_{5-95}) identified as most suitable duration metric

Pilot Study on Steel Braced Frame

Rotational Spring
Zero-length hinge
Modified Ibarra-Medina-Krawinkler bilinear model with in-cycle and cyclic degradation

Brace
Force-based fiber element
Giuffre-Menegotto-Pinto steel model with isotropic strain hardening and low-cycle fatigue effects (*Uriz & Mahin, 2004*)





~40% decrease in collapse capacity from 20s to 100s

Significant decrease in collapse capacity with duration

Actual rate of decrease found to depend on the chosen duration metric

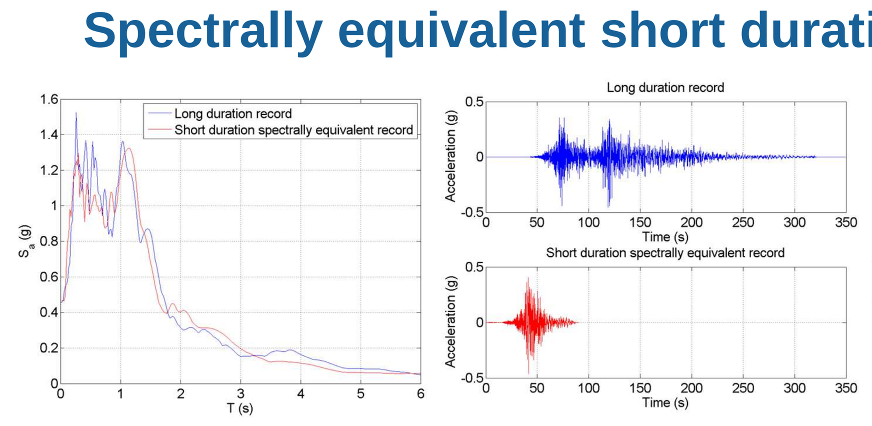
5-95% Significant duration (t_{5-95}) found to best capture this effect

Extended long duration record set

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

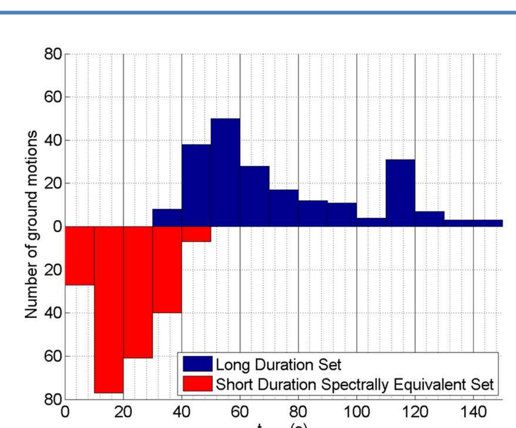
~2000 records ➡ Screened mean PGA < 0.1g, mean PGV < 10cm/s, t_{5-95} < 45s; Max 25 records from each event ➡ 106 records

Spectrally equivalent short duration record set



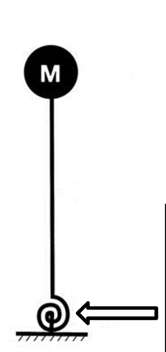
For every long duration ground motion, a corresponding short duration ground motion with similar spectral shape was chosen

Created as a control for the effect of spectral shape



Comparison of the durations of ground motions in both sets

Concrete Bridge Pier Model



Concrete column tested by PEER and NEES at UC San Diego

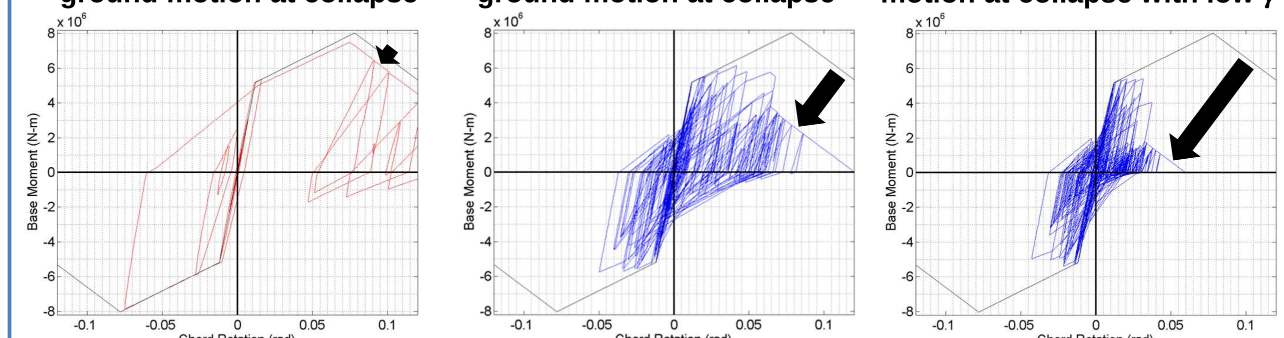
Modeled as an SDOF system

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

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

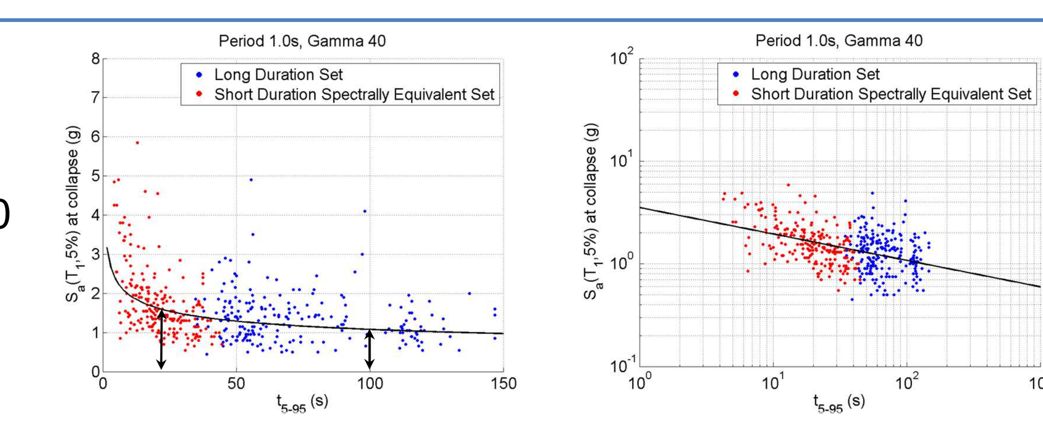
Deterioration governed by dissipated hysteretic energy as

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



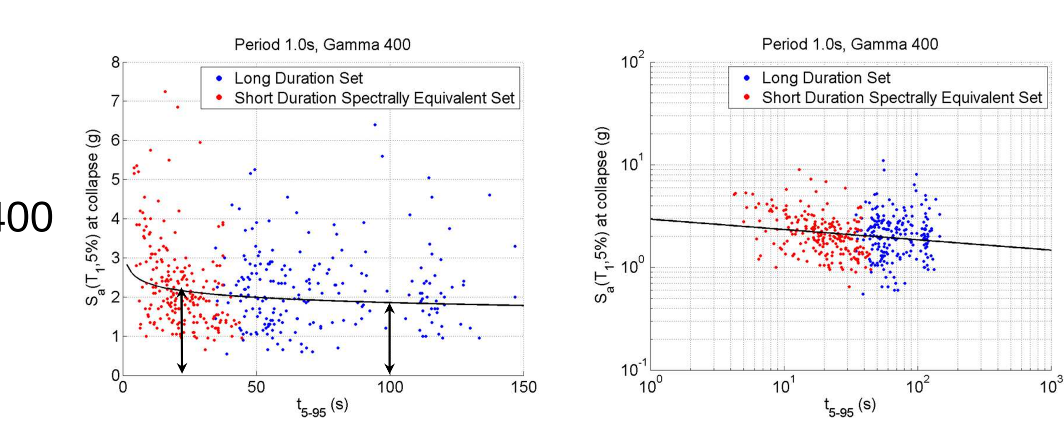
Value of γ expected to control effect of duration on collapse capacity
From calibration to test data, $T = 1.1s$, $\gamma = 120$
Analysis repeated for different periods and different values of γ

$\gamma = 40$



~35% decrease in collapse capacity from 20s to 100s

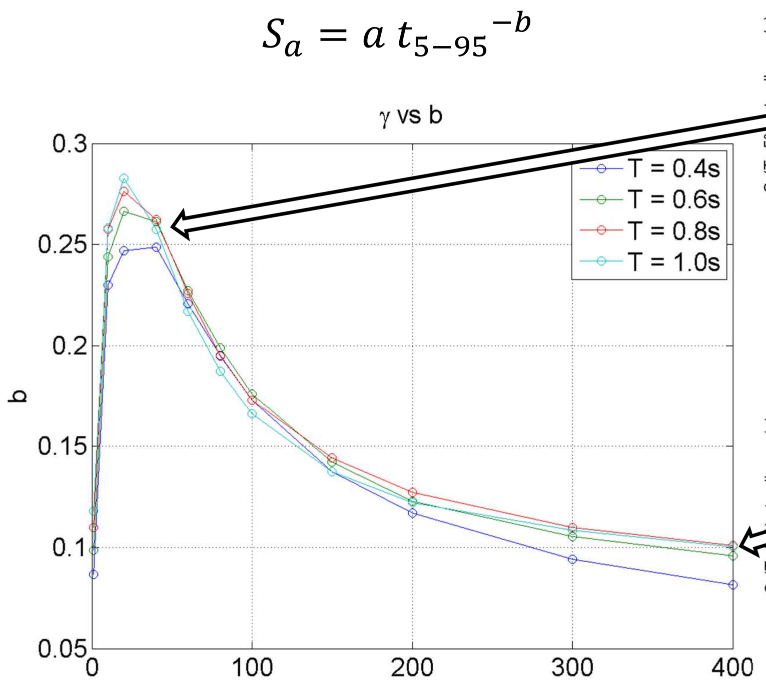
$\gamma = 400$

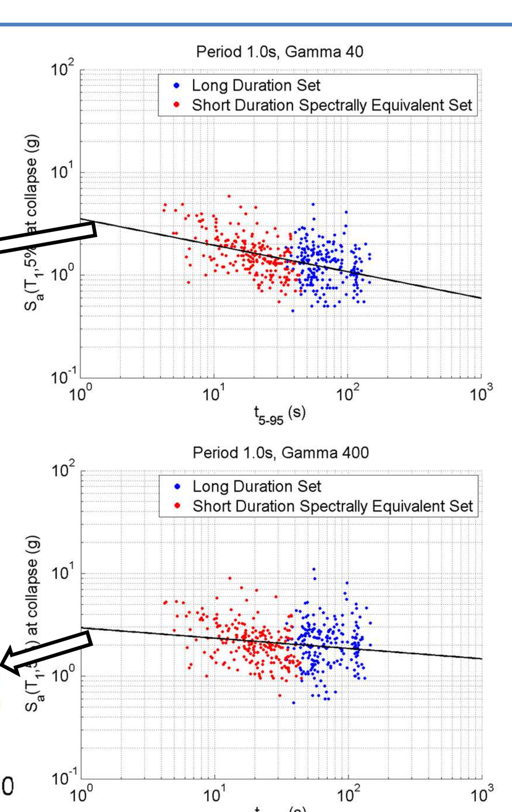


~15% decrease in collapse capacity from 20s to 100s

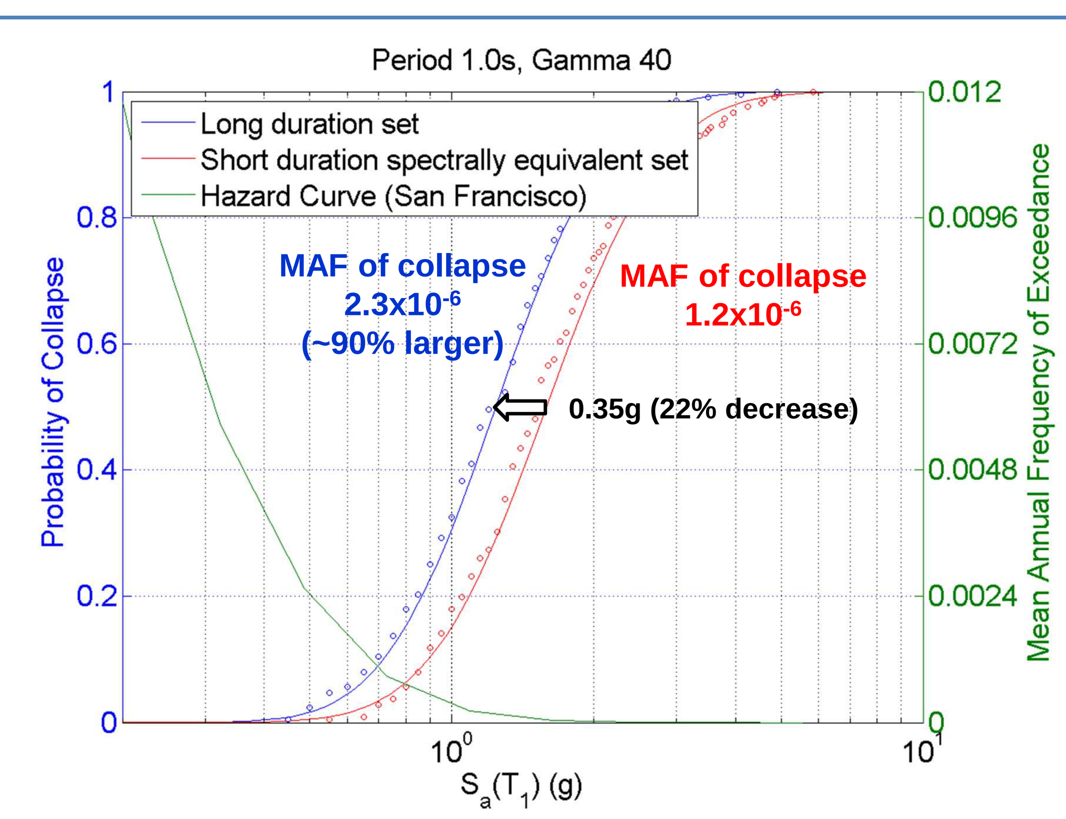
$$\ln(S_a) = \ln(a) - b\ln(t_{5-95})$$

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





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



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

Summary of Findings

Duration can have a significant effect on the collapse capacity of structures, depending on their hysteretic energy dissipation capacities

Reduction in collapse capacity from 20s to 100s
- Braced frame example: ~40%
- Concrete column example: ~35% (~90% increase in MAF of collapse)

Use of realistic (deteriorating) structural models and careful ground motion selection allowed for rigorous assessment of duration effects

5-95% Significant duration is the most effective duration metric

Future Work

Study the sensitivity of duration effects on other parameters used to characterize SDOF systems and then extend the study to MDOF bridge archetype models

Evaluate methods of incorporating duration effects into the PBEE framework, design provisions and cyclic loading protocols

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