Ground Motion Duration Effects on High-Strength Reinforcing Steel Fracture in Reinforced Concrete Structures

PEER Transportation Systems Research Program

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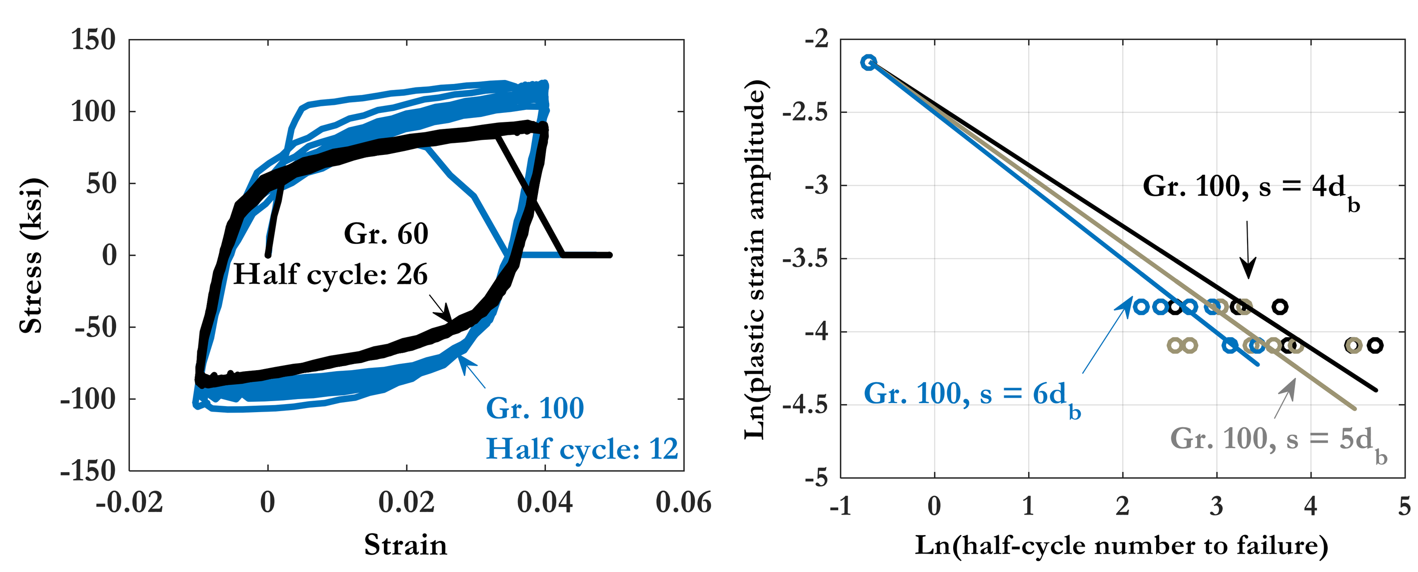
Background and Motivation

- Previous research efforts on spectrally-equivalent long and short duration ground motions (Chandramohan, Baker and Deierlein, 2017) have demonstrated that earthquake duration does influence structural collapse capacity.
- High-strength (HS) reinforcing steel, with benefits to constructability and cost-effectiveness, is bearing concern whether it has sufficient strain hardening and ductility to resist fracture.
- Premature fracture following fatigue is potentially more critical under long-duration ground motions.

Objectives

- Quantify duration effects on structural response demands, i.e., lateral drift, steel strain, and fracture potential.
- Incorporate duration effects into seismic performance assessment and design guidelines of reinforced concrete structures, i.e., buildings and bridges.

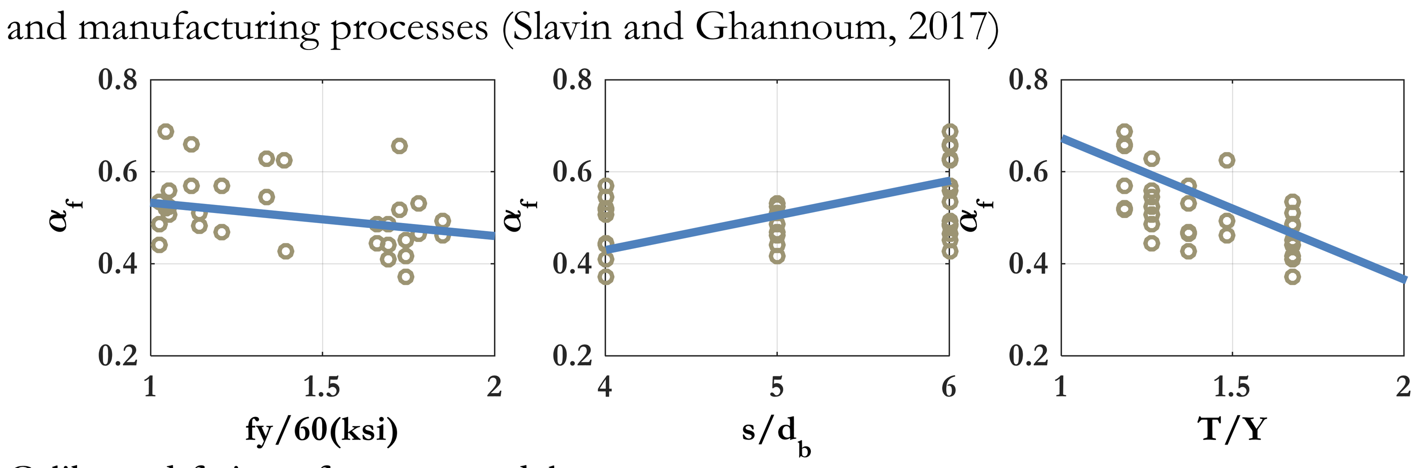
Low-Cycle Fatigue of HS Reinforcement



- Gr. 100 bars, in overall, showed 10% fewer half cycles to fatigue than Gr. 60.
- Fracture resistance also depends on manufacturing process techniques.
- Fatigue life is impacted by the slenderness (s/d_b): buckled bars are more prone to fracture.

Proposed Fatigue-Fracture Model

- Observed trend from 206 low-cycle fatigue tests with different grades, T/Y ratios, s/d_b's, and manufacturing processes (Slavin and Ghannoum, 2017)

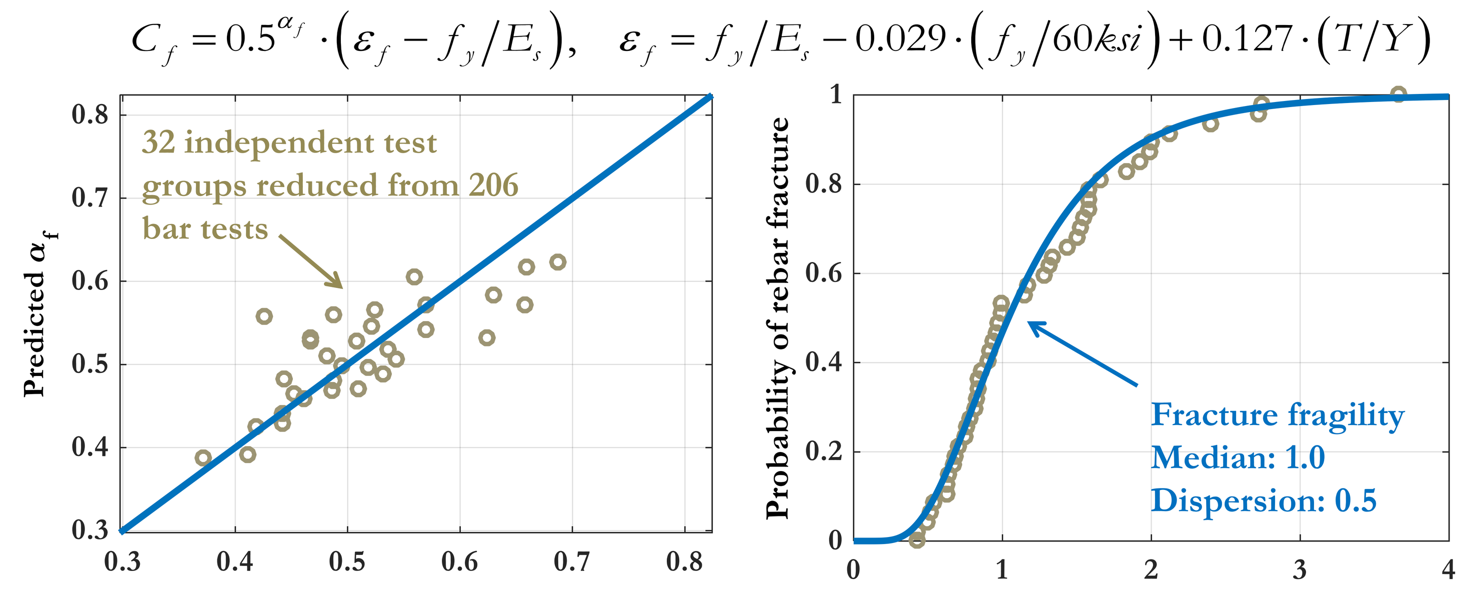


- Calibrated fatigue-fracture model:

$$FI = f\left(\varepsilon_{p,i}\right) = \sum_{i=1}^{N}\left(\frac{\varepsilon_{p,i}}{C_f}\right)^{1/\alpha_f}$$

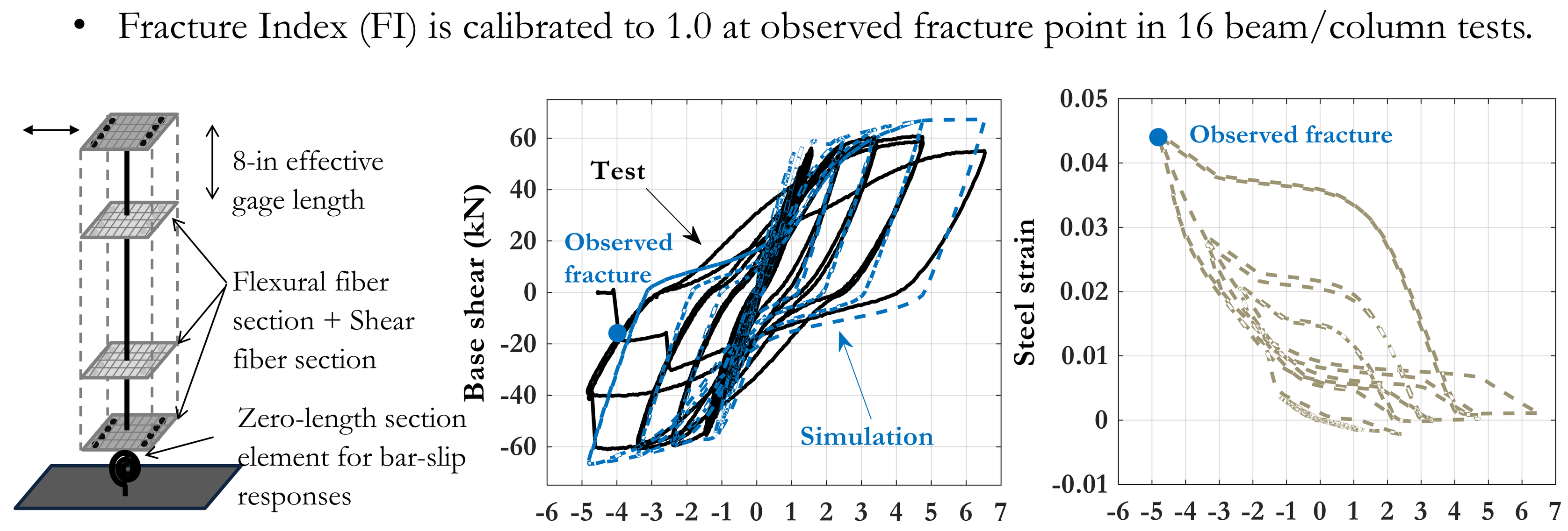
$$\alpha_f = 0.729 - 0.075\cdot\left(f_y/60ksi\right) + 0.038\cdot\left(s/d_b\right) - 0.217\cdot\left(T/Y\right),$$

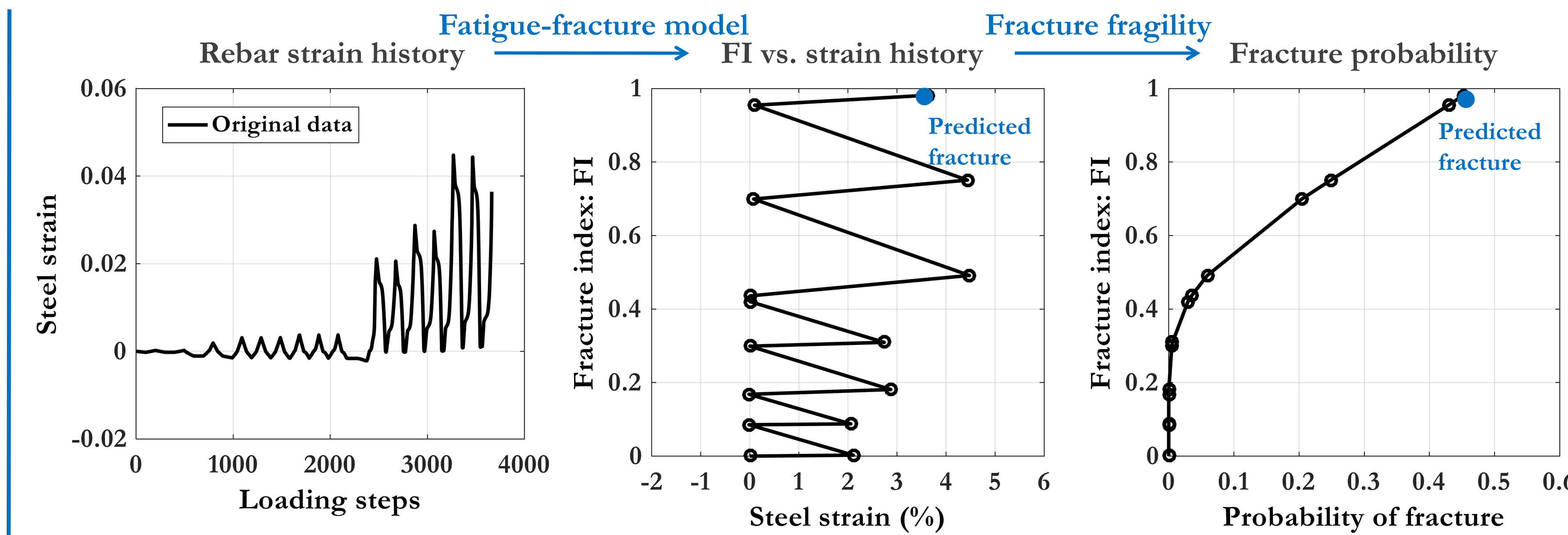
$$C_f = 0.5^{\alpha_f}\cdot\left(\varepsilon_f - f_y/E_s\right),\quad \varepsilon_f = f_y/E_s - 0.029\cdot\left(f_y/60ksi\right) + 0.127\cdot\left(T/Y\right)$$



Validation of Fatigue-Fracture Model

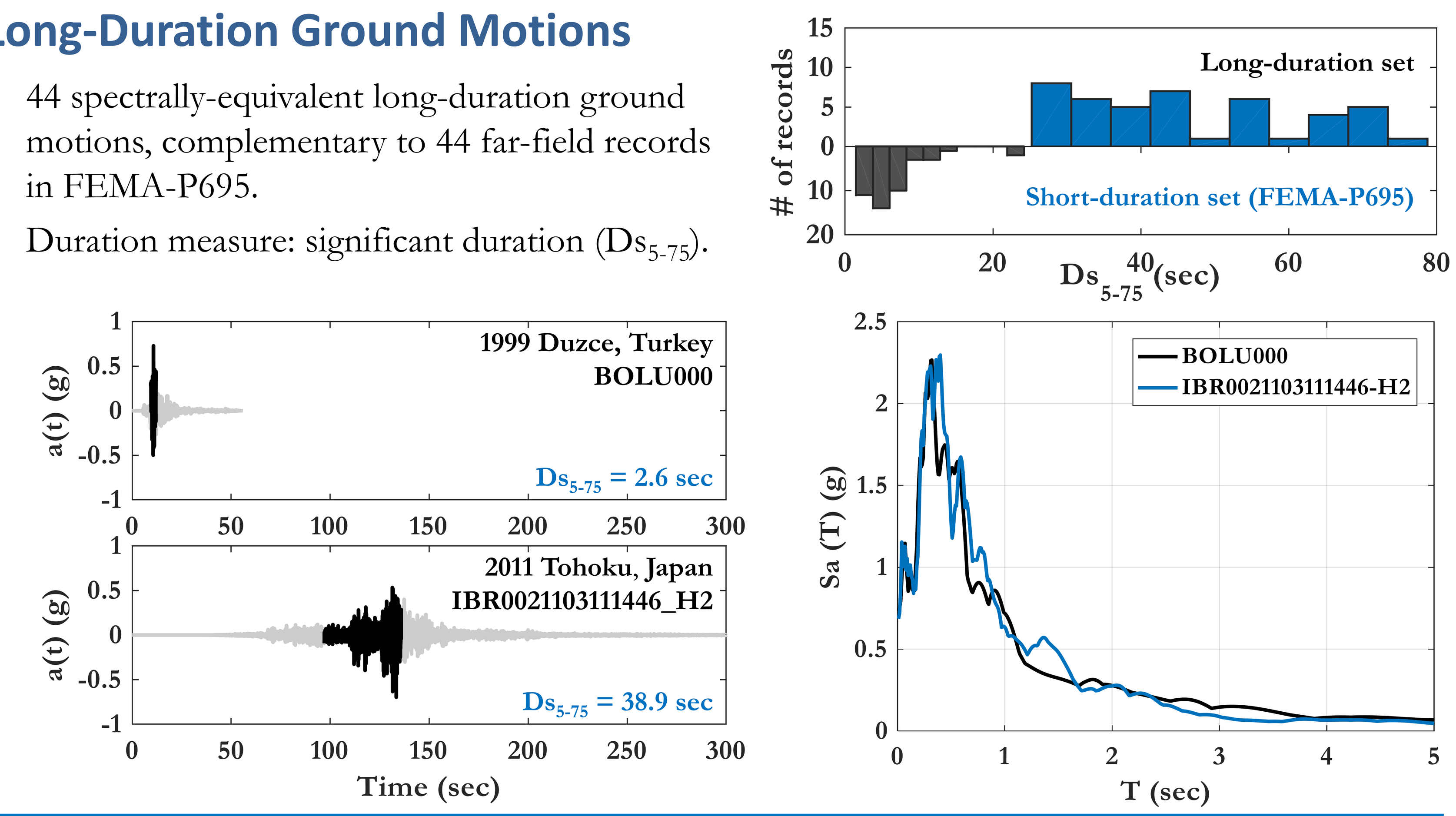
- Fiber element analyses: flexure + shear + bar-slip behavior
- Fracture Index (FI) is calibrated to 1.0 at observed fracture point in 16 beam/column tests.





Long-Duration Ground Motions

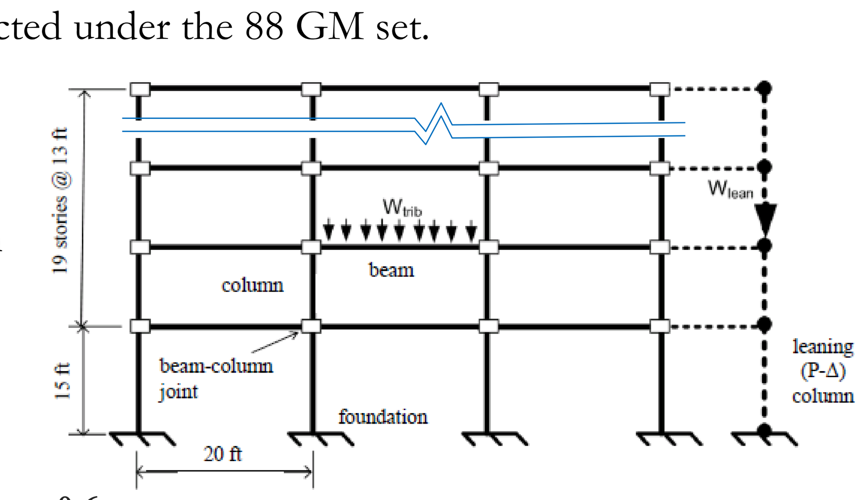
- 44 spectrally-equivalent long-duration ground motions, complementary to 44 far-field records in FEMA-P695.
- Duration measure: significant duration ($Ds_{5\text{-}75}$).



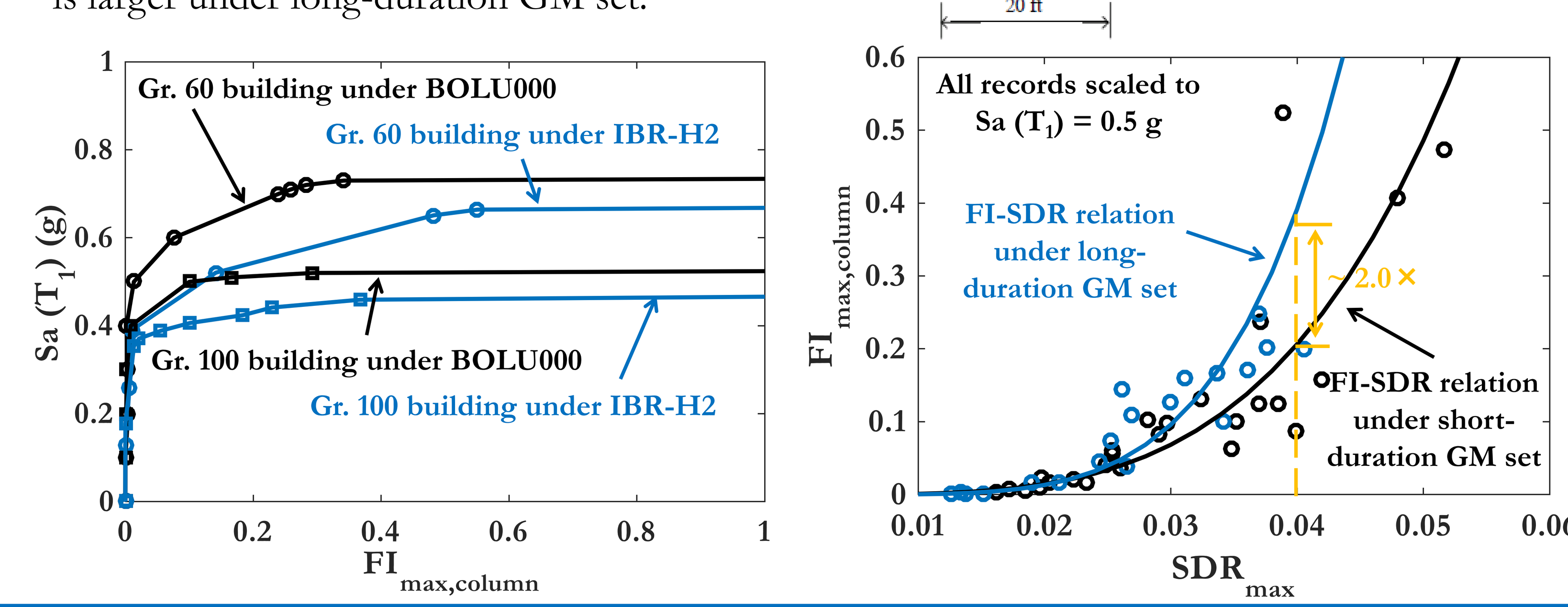
Example: 20-Story RC Frame

- Archetype 20-story RC frame in FEMA-P695 was redesigned with Gr. 100 reinforcement but to the same strength. IDA analyses were conducted under the 88 GM set.

Grade	T_1 (sec)
60	2.7
100	3.2



- Fracture potential is higher under long-duration records comparing to the one under short-duration records.
- At the same Sa (T_1) level and the same SDR, FI is larger under long-duration GM set.



Ongoing Studies: RC Bridge System

- Establish detailed fiber element models for bridge columns and calibrate both global and local responses to available test database. Extend the study of SDOF systems to MDOF bridge archetype models.
- Relate the fracture potential to story drift ratio demands and quantify the influence of duration on rebar fracture demands.
- Incorporate duration effects into seismic performance assessment and design guidelines of reinforced concrete bridges.

Summary

- A new rebar fatigue-fracture model was proposed and validated for assessing fracture probability with considerations of different steel grades, T/Y ratios, and s/d_b's.
- Duration has a significant impact on the rebar strain demands and fracture potential. In the presented frame case, the FI can be 100% higher under the long-duration GM set at SDR = 0.04.

Acknowledgement

This research is supported by the PEER – TSRP (S2), the Charles Pankow Foundation, and the Blume Center for Earthquake Engineering. The authors gratefully acknowledge researchers associated with ACI HS reinforcement working group. In particular, the authors thank Reagan Chandramohan, Wassim Ghannoum, Andreas LePage, Dominic Kelly, Andrew Taylor, David Fields, Ron Hamburger, and Jack Moehle for their support and help. Great appreciations Stanford/Blume Center for use of the Sherlock computing cluster at Stanford University.

This project was made possible with support from:

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