Characterising the influence of ground motion duration on structural strength and deformation capacity

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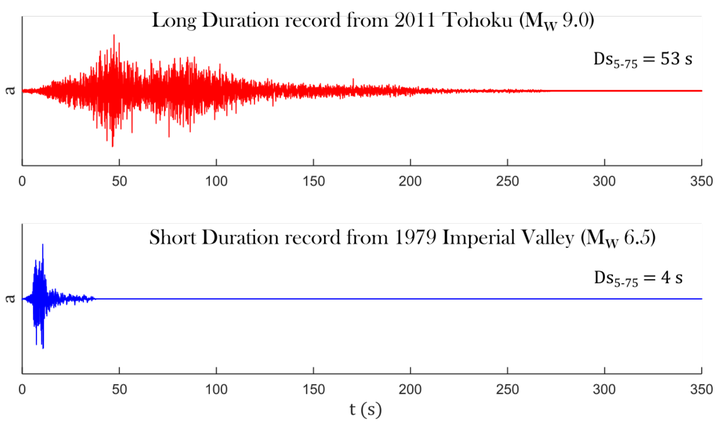
Background and Motivation

- Recent studies have demonstrated the effect of earthquake ground motion duration on structural collapse capacity. This effect is not explicitly considered in the design process.
- The effect of duration is more accurately captured by employing realistic, deteriorating structural models capable of simulating behaviour of structures at large nonlinear deformations by incorporating in-cycle and cyclic deterioration of strength and stiffness of structural components as well as destabilising P-Δ effects.

Objectives

- Characterise the influence of duration/cyclic demands on structural collapse and deformation capacity.
- Devise methods to consider the effect of duration/cyclic demands in seismic design.

Examples of long and short duration ground motions



- 5-75% Significant durations ($D_{S_{5-75}}$) of ground motion records from the 2011 Tohoku (M_W 9.0) earthquake were as long as 80 s.

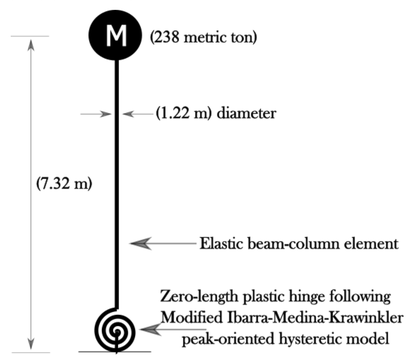
Methodology

- Traditional incremental dynamic analyses (IDA) are conducted using two spectrally equivalent sets (Long Duration and Short Duration) of 44 ground motions each. (PEER NGA-West2 database)
- The effect of duration on structural collapse capacity is observed through comparison of results from the two sets.
- Two structural models considered in the study are:
  (i) Reinforced concrete bridge column,
  (ii) Two-story reinforced concrete moment frame building.

Structural Models

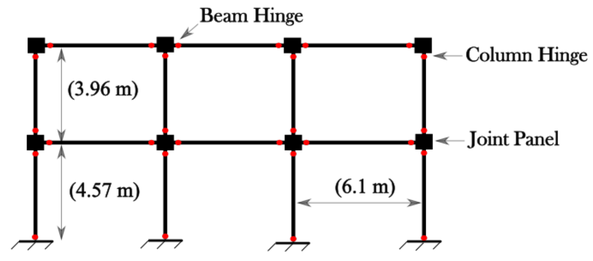
Reinforced Concrete Column

- Reinforced concrete (RC) column previously tested by PEER and NEES at UC San Diego is modelled as an SDOF system in OpenSees. (PEER 2010b)
- Defined as a linear elastic element connected to the base through a zero-length plastic hinge, following the Modified Ibarra-Medina-Krawinkler (IMK) peak-oriented model. Fundamental period: 1.20 s.



Reinforced Concrete Frame

- Two-story RC moment frame building with a fundamental period 0.53 s, designed for a site in Los Angeles is modelled in OpenSees as two-dimensional, three-bay space frame. (Raghunandan 2013)
- Plastic hinges are modelled at the joint panels to describe the flexural behaviour of beam-column members using the IMK peak-oriented model.



- Both models are capable of capturing different modes of strength and stiffness deterioration as well as geometric nonlinearities to carry out large displacement analyses.

Acknowledgements

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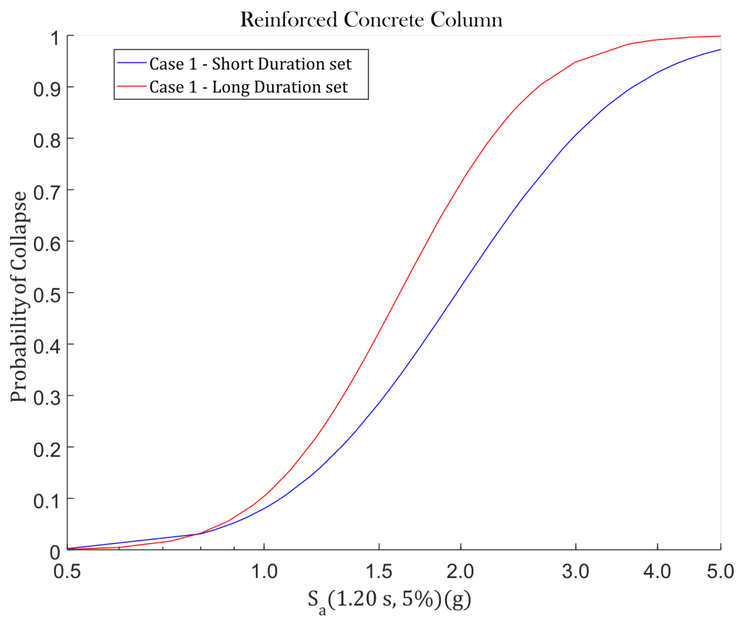
References

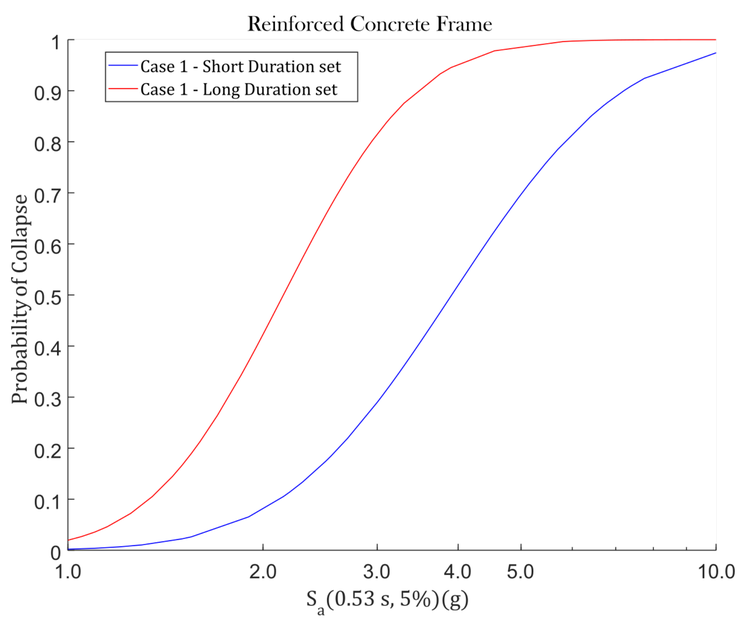
1. Ancheta, T.D. et al., 2013. PEER NGA-West2 Database, PEER 2013/03, Pacific Earthquake Engineering Research Center, Berkeley, CA.

2. Pacific Earthquake Engineering Research Center (PEER), 2010b. Concrete Column Blind Prediction Contest, Berkeley.

3. Raghunanadan, M., 2013. Influence of long duration ground shaking on collapse of reinforced concrete structures, University of Colorado, Boulder.

Effect of Duration on Collapse Capacity: Role of Model Parameters



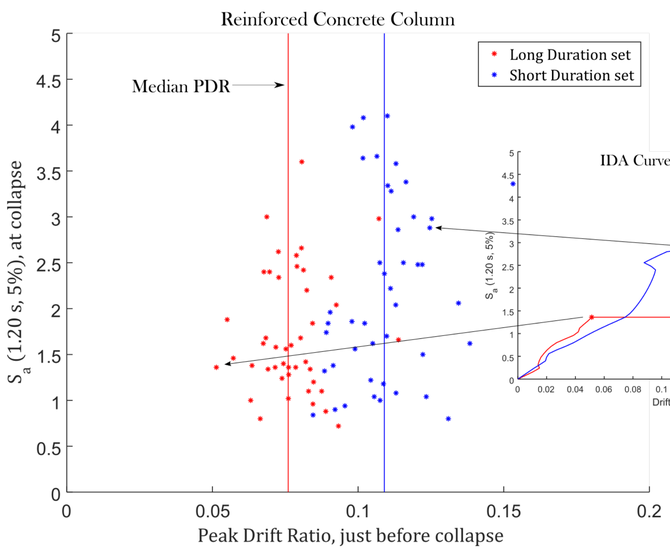


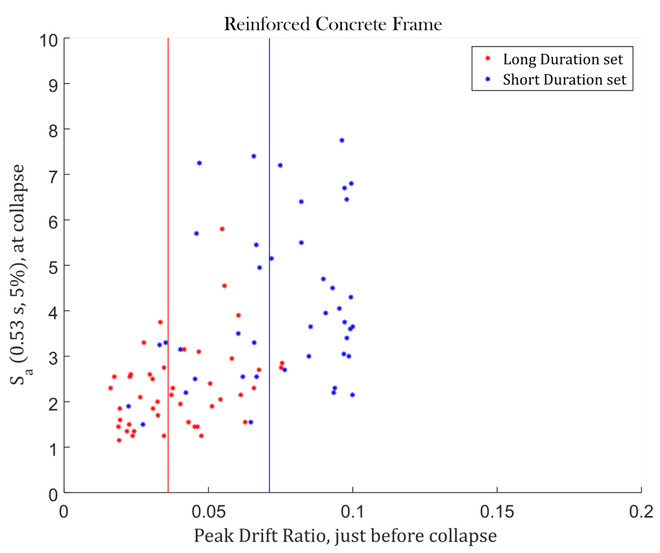
Median Collapse Capacity (g)

Model Incorporates			Reinforced Concrete Column			Reinforced Concrete Frame		
Case No.	Deterioration	P-Δ effects	Short Duration (SD)	Long Duration (LD)	Decrease	Short Duration (SD)	Long Duration (LD)	Decrease
1	✓	✓	1.96	1.62	17 %	3.91	2.15	45 %
2	✓	✗	2.43	1.83	25 %	3.95	2.06	48 %
3	✗	✓	2.13	1.99	6 %			

- The effect of duration on Median Collapse Capacity is mainly observed when features of cyclic deterioration are incorporated in the model, as 25 % and 48 % lower values are recorded for the two models under long duration set. P-Δ effects do not seem to have a significant impact on the observed effects of duration for the considered cases.

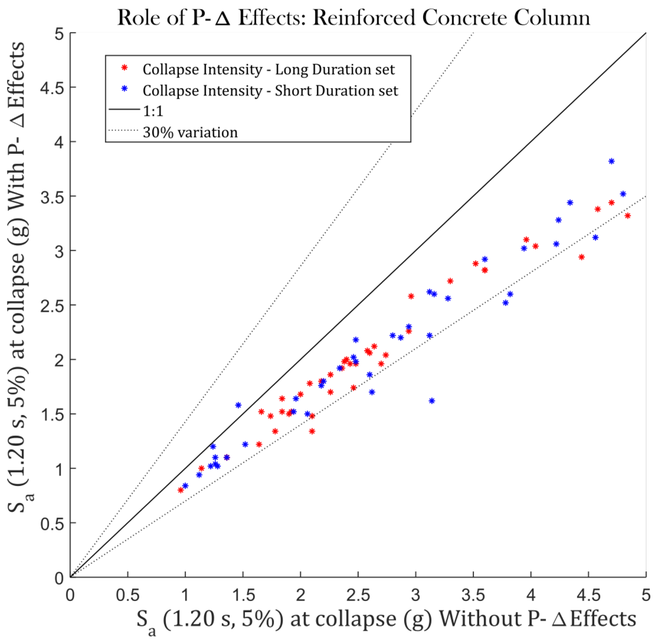
Drift Demand at Collapse

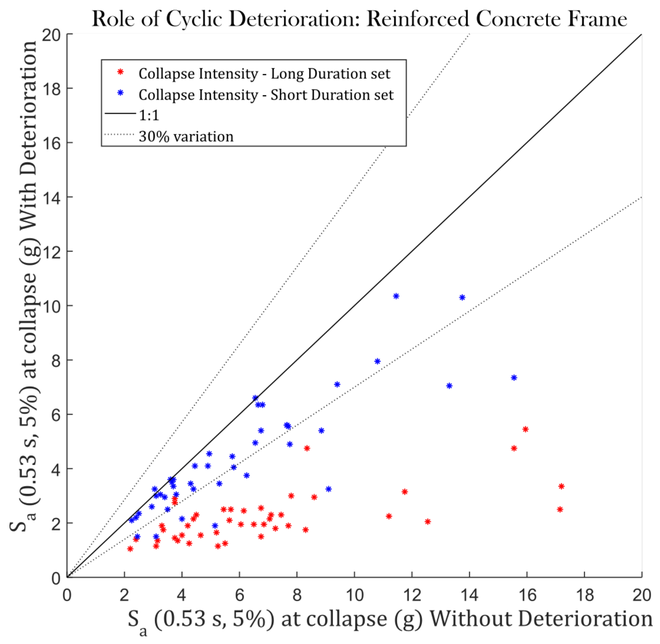




- Long duration ground motions can cause structures to collapse at much smaller drift demands. The median Peak Drift Ratio (PDR) values recorded at the onset of collapse are 30 % and 49 % smaller for the two considered cases under the long duration set. This indicates towards lower "dynamic" deformation capacity of structures under long duration records and underlines the importance of consideration of "duration" in seismic design guidelines..

Role of Cyclic Deterioration (CD) and P-Δ effects





- For the two considered cases, P-Δ effects seem to have a uniform impact on the structure, irrespective of the record duration. This can be attributed to better re-centering capability of the hysteretic model employed and less susceptibility of the considered low-rise structures to ratcheting collapse.
- The impact of cyclic and in-cycle deterioration is observed to be significantly larger under longer durations, due to large hysteretic energy dissipation. This is found to be the main phenomenon causing the effect of duration on structural collapse capacity for the present cases.

Conclusions and Future Work

- Duration indeed has a significant impact on the collapse capacity of structures, causing collapse at lower intensities due to large hysteretic energy dissipation and cyclic deterioration. This effect observed is higher for the two-story frame than for the bridge column and needs further investigation to understand the reasons behind it.
- Lower drift demands recorded prior to total collapse under long duration ground motions demonstrate the influence of duration on structural deformation capacity.
- P-Δ effects are not found to be contributing towards the observed effect of duration for the low-rise structures considered in the present study. However, it will be of interest to extend the investigation to mid-rise and high-rise structures.
- As the current phenomenological plastic hinge models in use were calibrated through tests using short duration loading protocols. It will be useful to examine the validity of using such loading protocols to test components likely to experience long duration ground motions and subsequent development of long duration loading protocols.