Influence of ground motion duration on the dynamic deformation capacity of reinforced concrete frame structures

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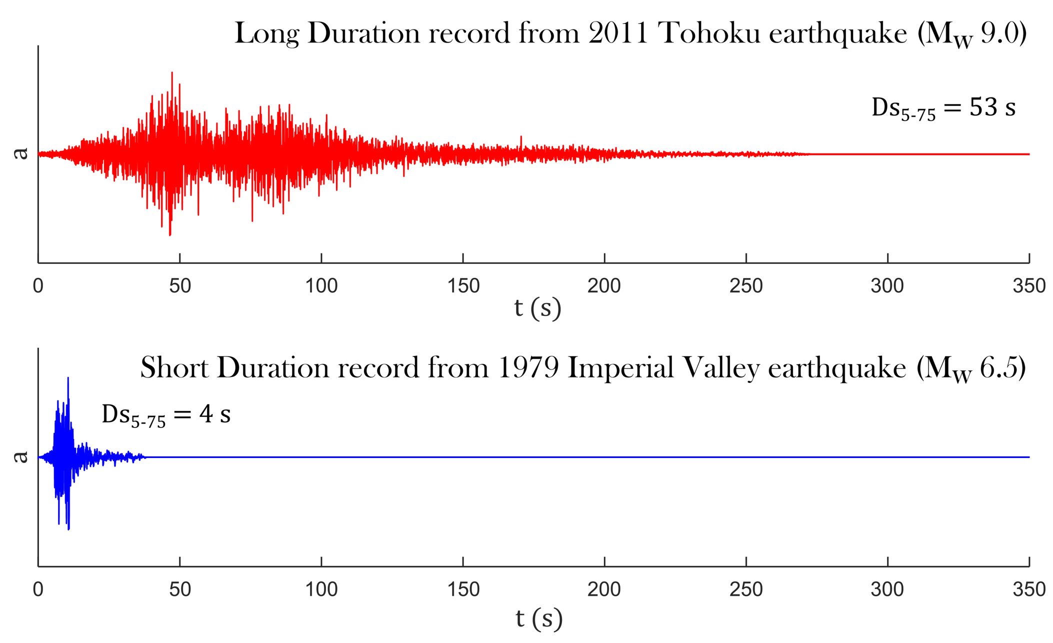
Background and Motivation

- Recent studies have demonstrated an increased likelihood of structural collapse under longer duration ground motions. This effect is not explicitly considered in current design and assessment guidelines.
- Although numerical studies have generally found no significant influence of duration on peak *deformation demands*, experimental tests have consistently reported lower *deformation capacities* of structural components under longer duration loading protocols/ground motions.

Objectives

- Develop a robust numerical procedure to estimate the dynamic deformation capacity of a structure.
- Characterise the influence of ground motion duration on structural dynamic deformation capacity.
- Devise methods to incorporate the observed effect of duration in seismic design and assessment guidelines.

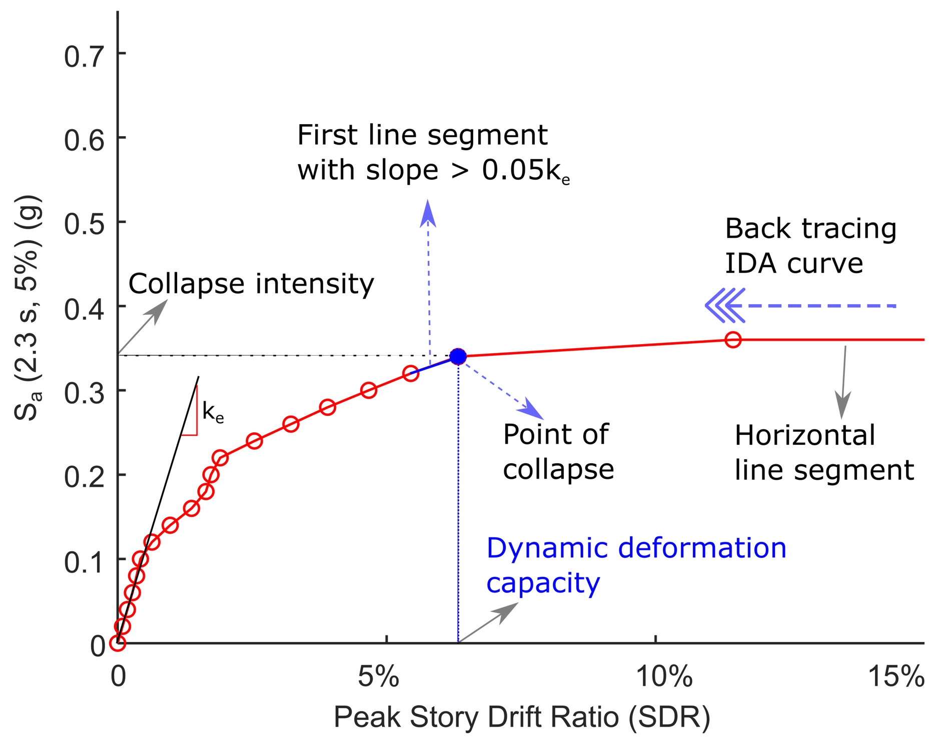
Examples of long and short duration ground motions



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

Dynamic Deformation Capacity

- The dynamic deformation capacity of a structure is estimated as the largest story drift ratio (SDR) simulated when conducting incremental dynamic analysis (IDA), at ground motion intensity levels lower than or equal to the collapse intensity.



- Collapse intensity is defined as the intensity corresponding to the starting point of the first line segment whose slope is greater than 5% of the initial elastic slope (k_e) of the IDA curve, when tracing the IDA curve backwards from the horizontal segment.
- The proposed method to estimate dynamic deformation capacity is robust against IDA curve "hardening". The accuracy of the estimated capacity is improved by reducing the intensity measure increments used to conduct IDA, especially the first increment and the increments near the collapse intensity.

Acknowledgements

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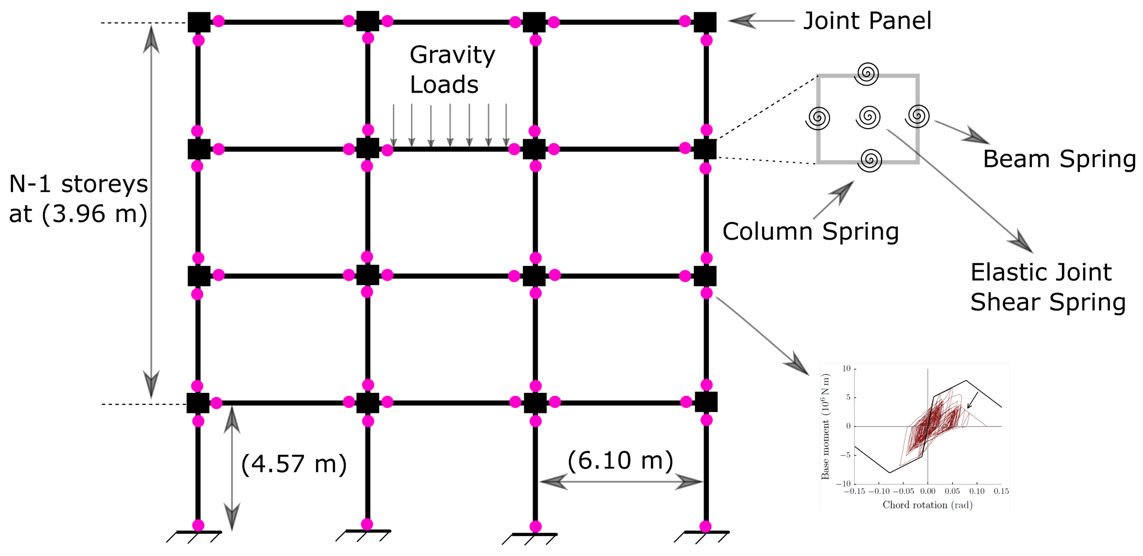
References

1. Haselton et al., 2010. Seismic collapse safety of reinforced concrete buildings. I: Assessment of ductile moment frames. Journal of Structural Engineering.
2. Raghunandan et al., 2015. Collapse risk of buildings in the Pacific northwest region due to subduction earthquakes. Earthquake Spectra.
3. Bhanu et al., 2019. Influence of ground motion duration on the dynamic deformation capacity of reinforced concrete frame structures. Earthquake Spectra. Manuscript in preparation.

Models of Reinforced Concrete Frame Structures

- 10 buildings ranging in height from 2 to 20 stories were considered. These were previously designed according to the provisions of the current 2012 International Building Code and analysed by Raghunandan et al. (2015) and Haselton et al. (2010).

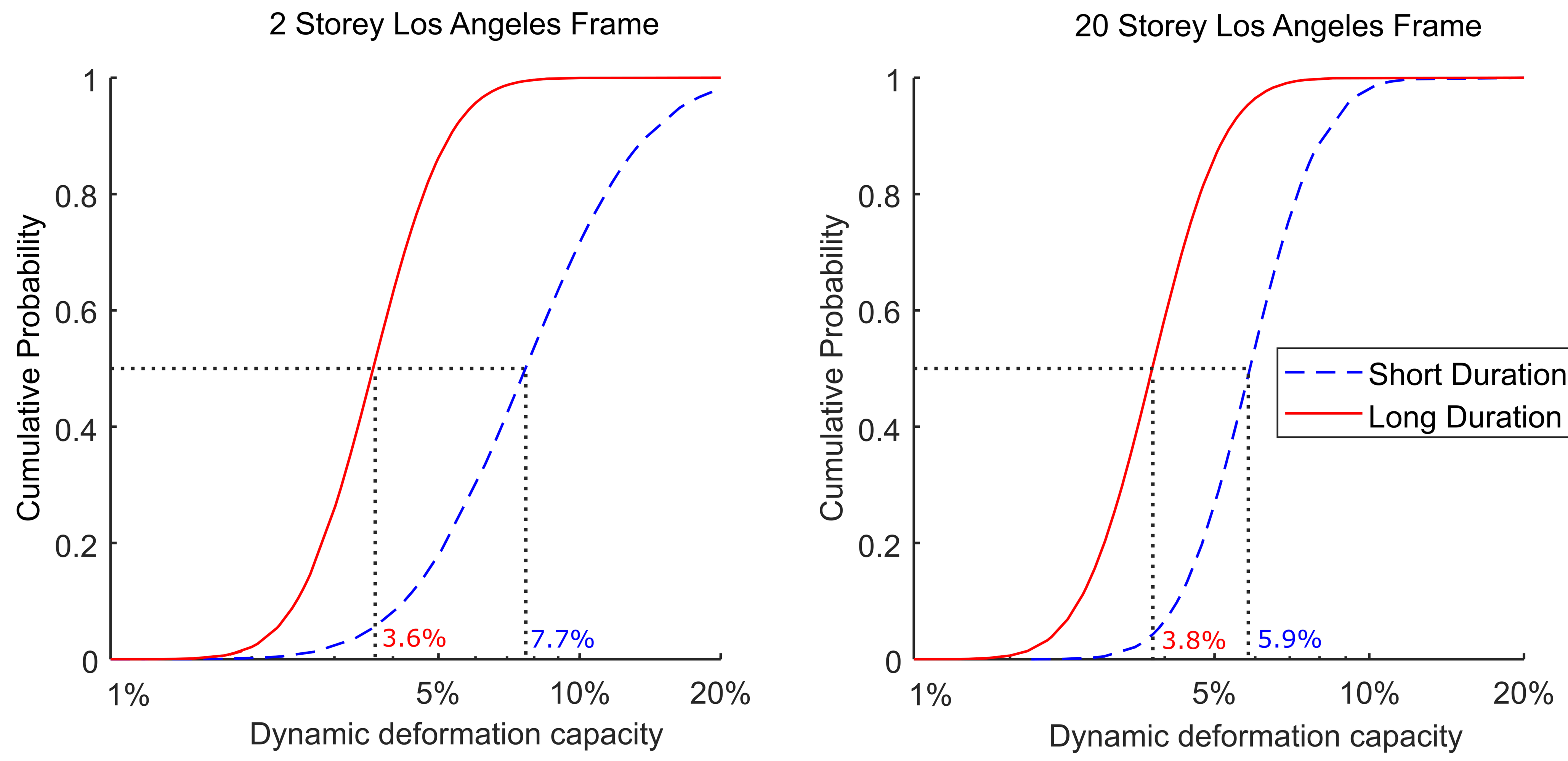


Site	Design MCE_R ordinates	No. of storeys	T_1 (s)
Los Angeles	S_s = 2.40 g S_1 = 0.84 g	2	0.53
		4	0.85
		8	1.53
	S_s = 1.50 g S_1 = 0.60 g	12	2.09
		20	2.31
Seattle	S_s = 1.37 g S_1 = 0.53 g	2	0.57
		4	0.98
		8	1.76
Portland	S_s = 0.98 g S_1 = 0.42 g	2	0.61
		8	1.93

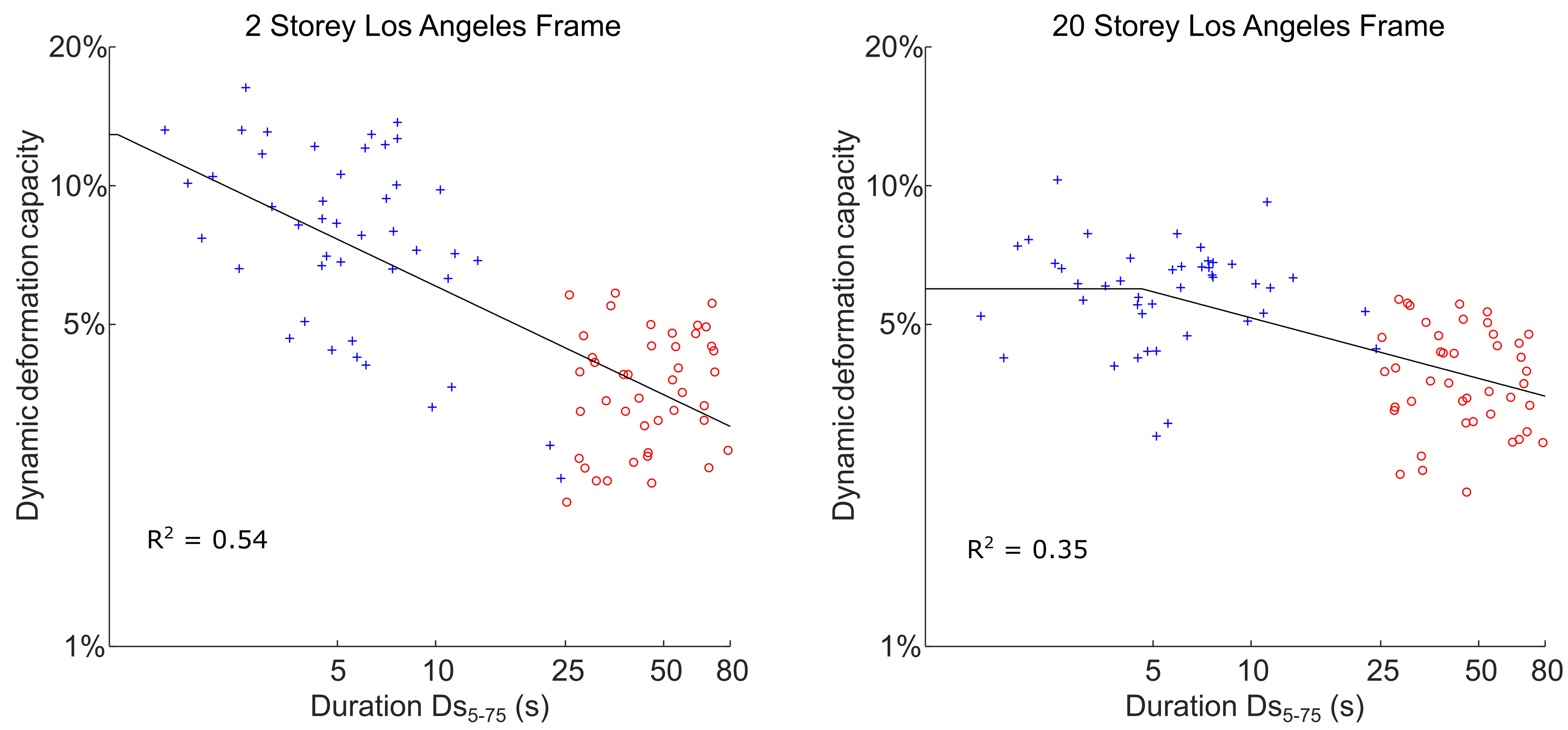
- Two-dimensional concentrated plastic hinge models of the archetype buildings were developed in OpenSees. The hysteretic behaviour of the plastic hinges was modelled using the Ibarra-Medina-Krawinkler peak-oriented model.
- The models incorporate the in-cycle and cyclic degradation of strength and stiffness of structural components, and the destabilising P-Δ effect of gravity loads, to adequately capture the effect of duration on structural response.

Influence of Duration on Dynamic Deformation Capacity

- The structural models were analysed using 2 sets of 44 short and 44 long duration ground motions.



- The median dynamic deformation capacity of the two-storey Los Angeles frame is estimated to be 3.6% and 7.7% using the long duration and short duration sets respectively. For the twenty-storey Los Angeles frame, it is estimated to be 3.8% and 5.9% respectively. The reduction in median dynamic deformation capacity of 53% and 35% under the long duration ground motions, for the two- and twenty-story RC frames respectively, can be characterised as the effect of duration. Similar results are observed for the other structures.



- The variation in dynamic deformation capacity with duration is investigated by plotting deformation capacity against Ds_{5-75}. Considering that deformation capacity is not expected to increase indefinitely under extremely short duration ground motions, a bilinear regression model is fit to the data points on logarithmic scales.

$$\ln \text{Dynamic Deformation Capacity} = \begin{cases} c_0 + \epsilon, & Ds_{5-75} \le 2T_1 \\ a(\ln Ds_{5-75}) + c_1 + \epsilon, & Ds_{5-75} > 2T_1 \end{cases}$$

- The critical duration value is expected to be related to the fundamental modal period of the structure, since the period determines the number and range of deformation cycles experienced, which in turn controls the influence of duration on structural response. In this study, the critical duration value is selected as $2T_1$.
- The coefficients of determination (R^2) of the regression models fall in the range of 0.33-0.54 for all structures.
- Considering the example of the two-story Los Angeles frame, a ten-fold increase in Ds_{5-75} (from 5 s to 50 s) reduces the dynamic deformation capacity by 54% (from 7.5% to 3.5%) on average.
- Unlike collapse capacity, dynamic deformation capacity is not found to be influenced by ground motion response spectral shape, quantified by $S_a Ratio$.

Conclusions

- The dynamic deformation capacities of the analysed structures estimated using the long duration set were found to be 43% lower than those estimated using the short duration set, on average. A consistent decreasing trend in deformation capacity with durations (longer than a critical duration) was also observed from regression models fit to the data.
- In general, a larger effect of duration was observed in shorter period structures, which experience a larger number of deformation cycles, leading to a faster rate of deterioration.
- The findings of this study provide the basis for a method to account for the effect of duration by modifying the structural deformation capacities based on anticipated durations.