Influence of ground motion duration on structural dynamic deformation capacity

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Background and motivation

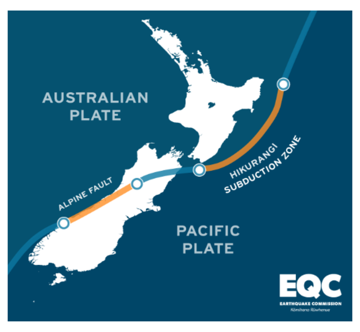
- Recent studies have demonstrated an increased likelihood of structural collapse under longer duration ground motions.
- Although numerical studies have generally found no significant influence of duration on peak *deformation demands*, experimental tests have consistently reported lower *deformation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

Objectives

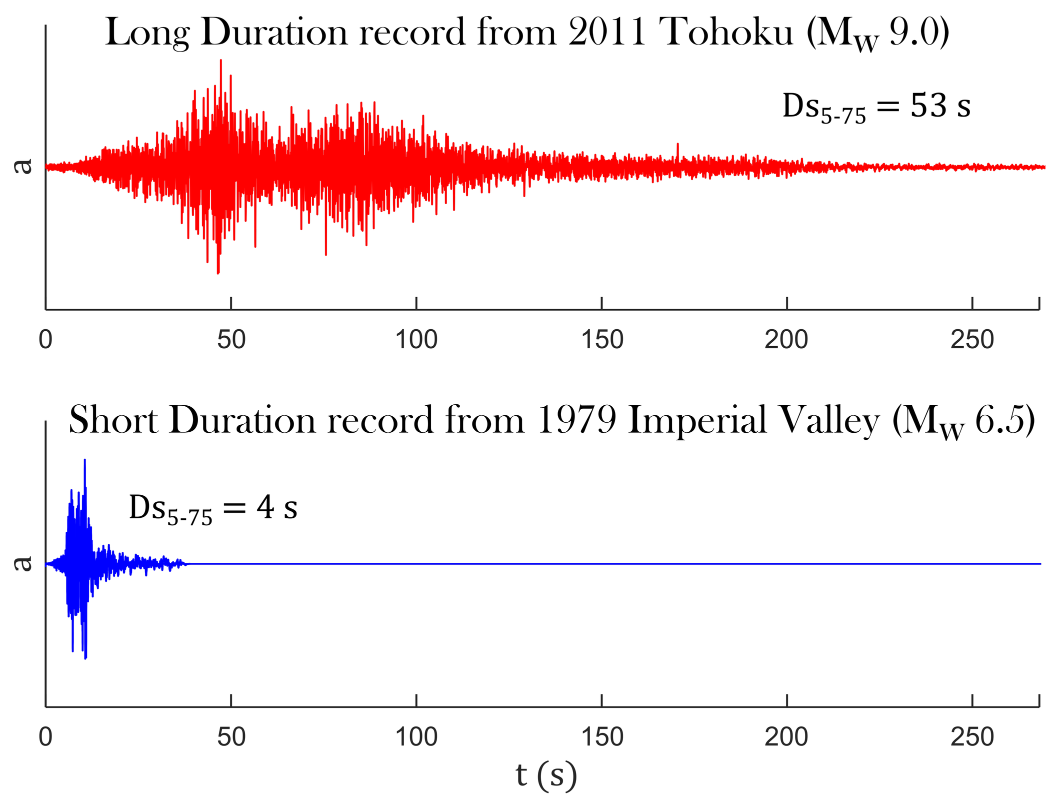
- Develop a robust numerical procedure to estimate the dynamic deformation capacity of a structure.
- Characterise the influence of ground motion duration on structural dynamic deformation capacity.
- Devise methods to incorporate the observed effect of duration in seismic design and assessment standards/guidelines.

Risks in New Zealand

- In New Zealand, possible large magnitude events on the Alpine Fault (M_W 8.0) and the Hikurangi Subduction Zone (M_W 8.9) expose certain areas to the risk of long duration ground motions.



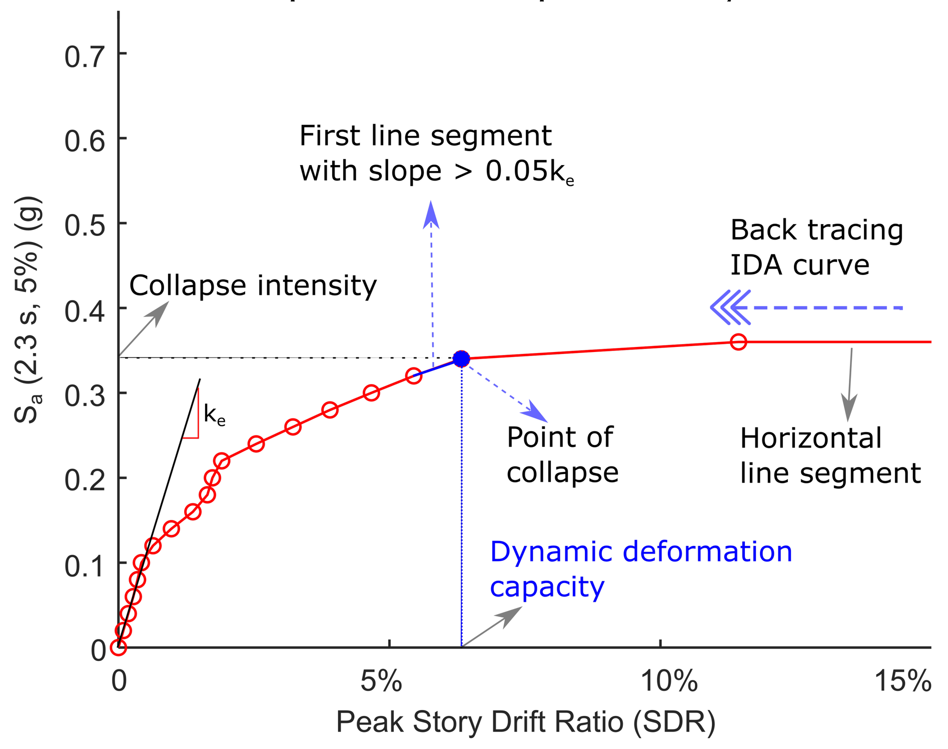
Examples of long and short duration ground motions



- 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 either greater than 5% of the initial elastic slope (k_e) of the IDA curve or negative, 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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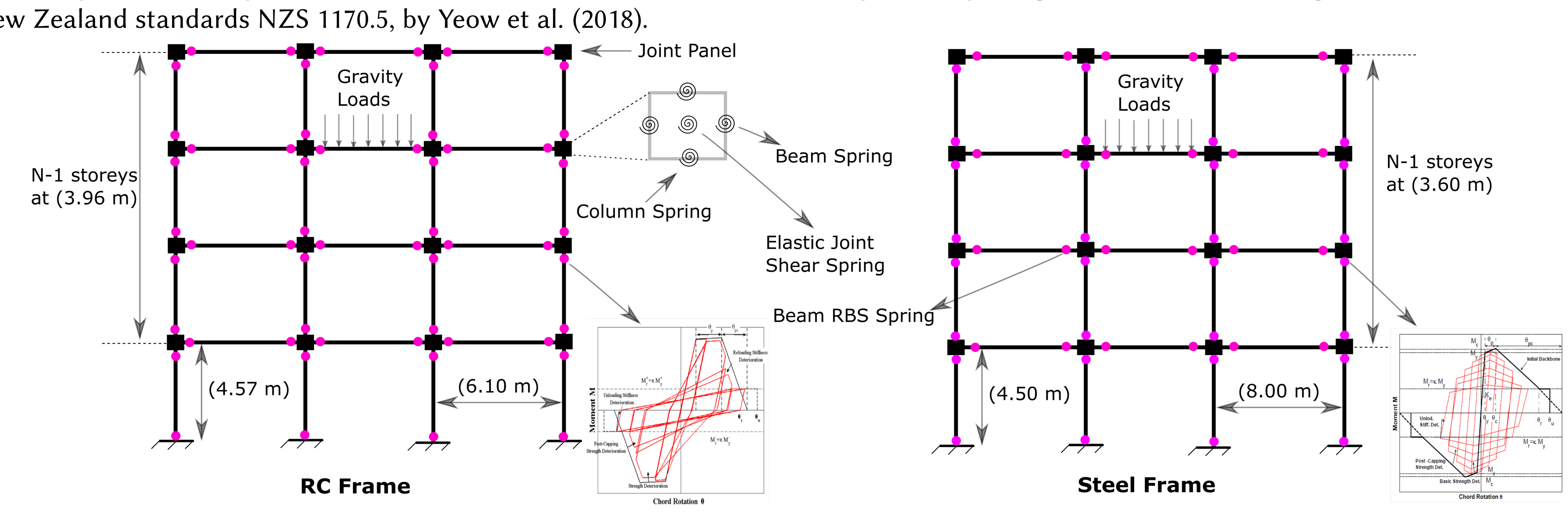
References

1. Bhanu et al., 2020. Influence of ground motion duration on the dynamic deformation capacity of reinforced concrete frame structures. *Earthquake Spectra (Submitted).*
2. Bhanu et al., 2020 Influence of ground motion duration on the dynamic deformation capacity of steel frame buildings. *WCEE 2020, Sendai, Japan.*

Models of Reinforced Concrete (RC) and Steel Frame Structures

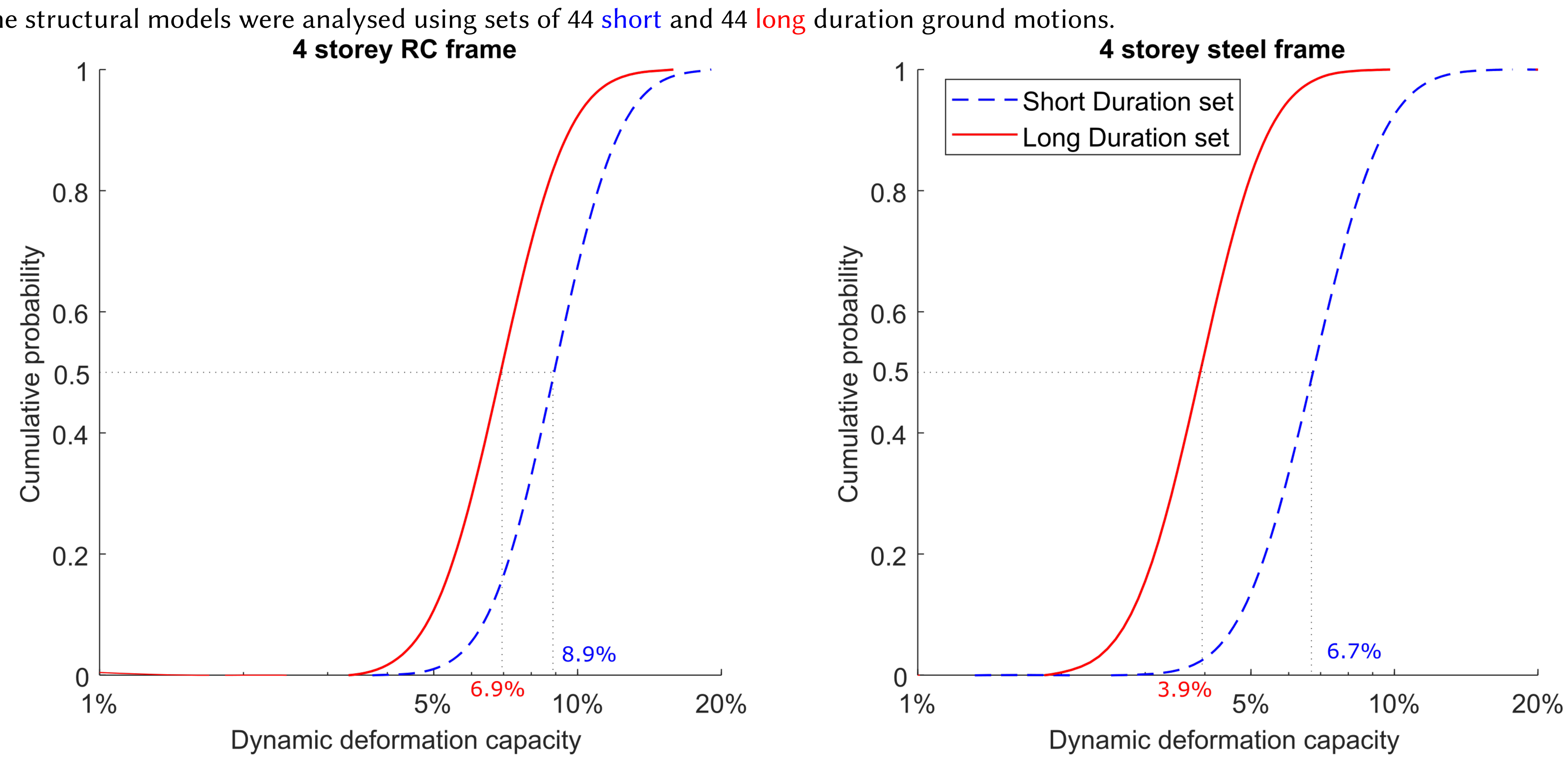
- 10 RC moment frames ranging in height from 2 to 20 storeys were considered. These were previously designed according to the provisions of the current 2012 International Building Code for different sites in the USA, and analysed by Raghunandan et al. (2015) and Haselton et al. (2010).
- A 4-storey and 12-storey steel moment frames were considered. These were previously designed for a site in Wellington in accordance with New Zealand standards NZS 1170.5, by Yeow et al. (2018).



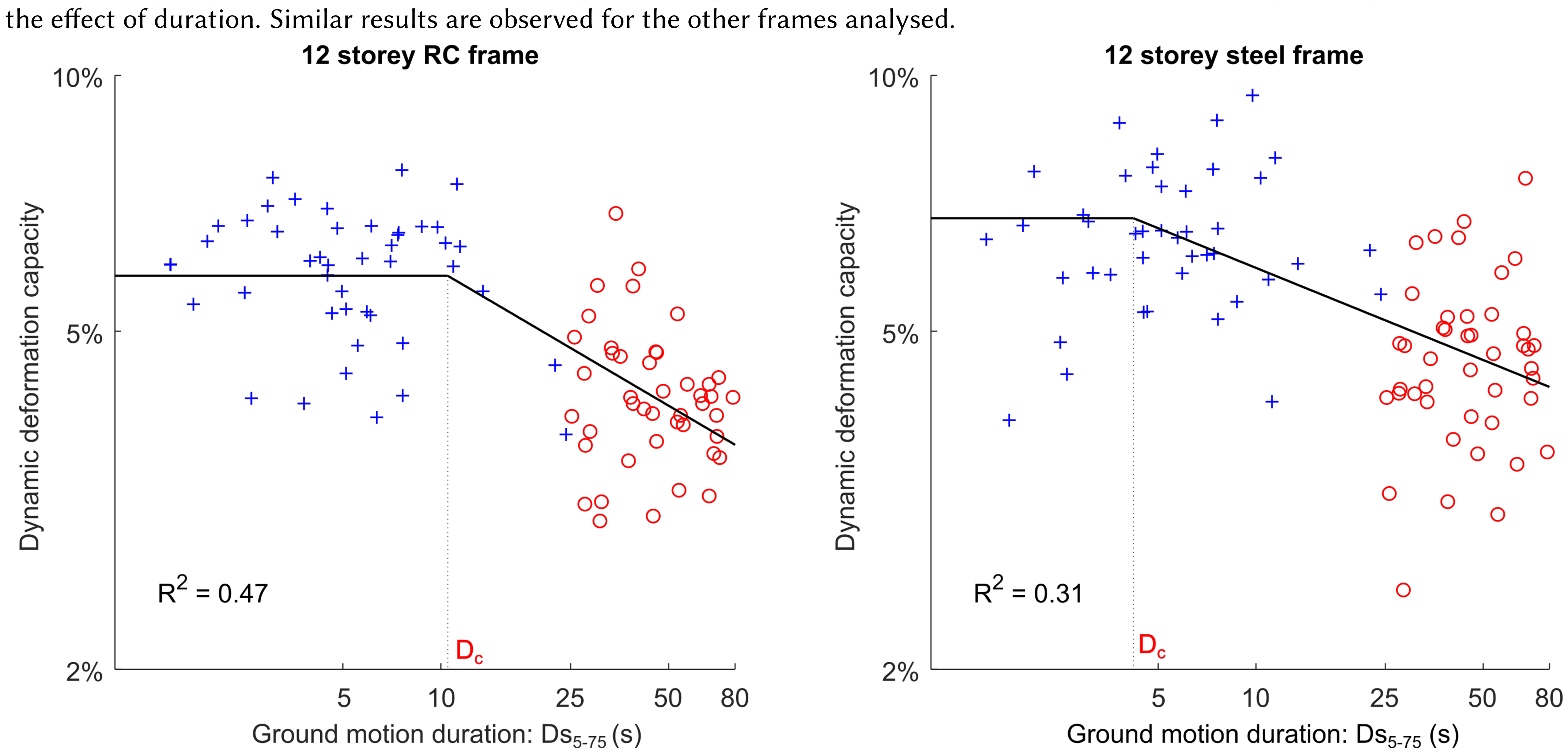
- Two-dimensional concentrated plastic hinge models of the frames were developed in OpenSees. The hysteretic behaviour of the plastic hinges was modelled using the Ibarra-Medina-Krawinkler peak-oriented model for RC frames, and the bilinear model for steel frames.
- The models incorporate the in-cycle 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 sets of 44 short and 44 long duration ground motions.



- The median dynamic deformation capacity of the 4-storey RC frame is estimated to be 6.9% and 8.9% using the long duration and short duration sets respectively. For the 4-storey steel frame, it is estimated to be 3.9% and 6.7% respectively. The reduction in median dynamic deformation capacity of 23% and 42% under the long duration ground motions, for the RC and steel frames respectively, can be characterised as the effect of duration. Similar results are observed for the other frames analysed.



- The variation in dynamic deformation capacity with duration is investigated by plotting deformation capacity against Ds_{5-75}. Since the 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.

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

- The critical duration value (D_c) 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, D_c is selected as $2T_1$ for steel frames and $5T_1$ for RC frames as this provides the best coefficients of determination (R^2) values, on average, for the regression model.
- The coefficients of determination (R^2) of the regression models fall in the range of 0.31-0.53 for all structures.
- 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 10 RC frames and 2 steel frames estimated using the long duration set were found to be 26% and 36% respectively lower than those estimated using the short duration set, on average. A consistent decreasing trend was observed in deformation capacity with ground motion duration (longer than a critical duration).
- The findings of this study provide the basis for a method to account for the effect of duration in seismic design and assessment standards/guidelines by modifying structural deformation capacities based on durations of the anticipated ground motions.