Development of Loading Protocols for Quasi-Static Testing

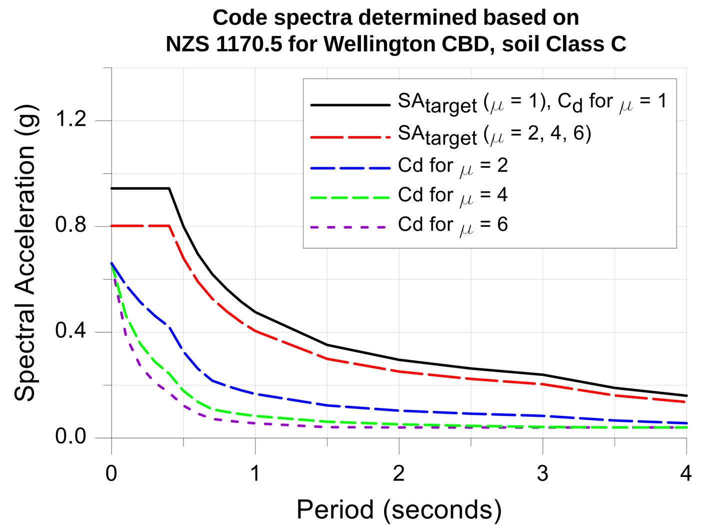
Christopher J. Motter[1], Kenneth J. Elwood[1]

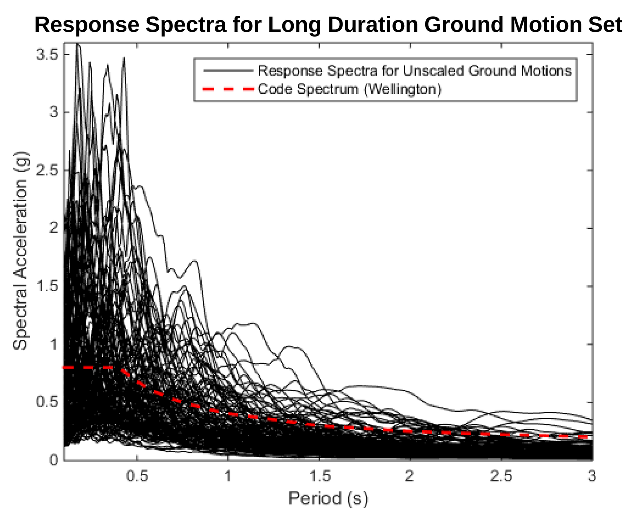
[1]University of Auckland

Introduction:

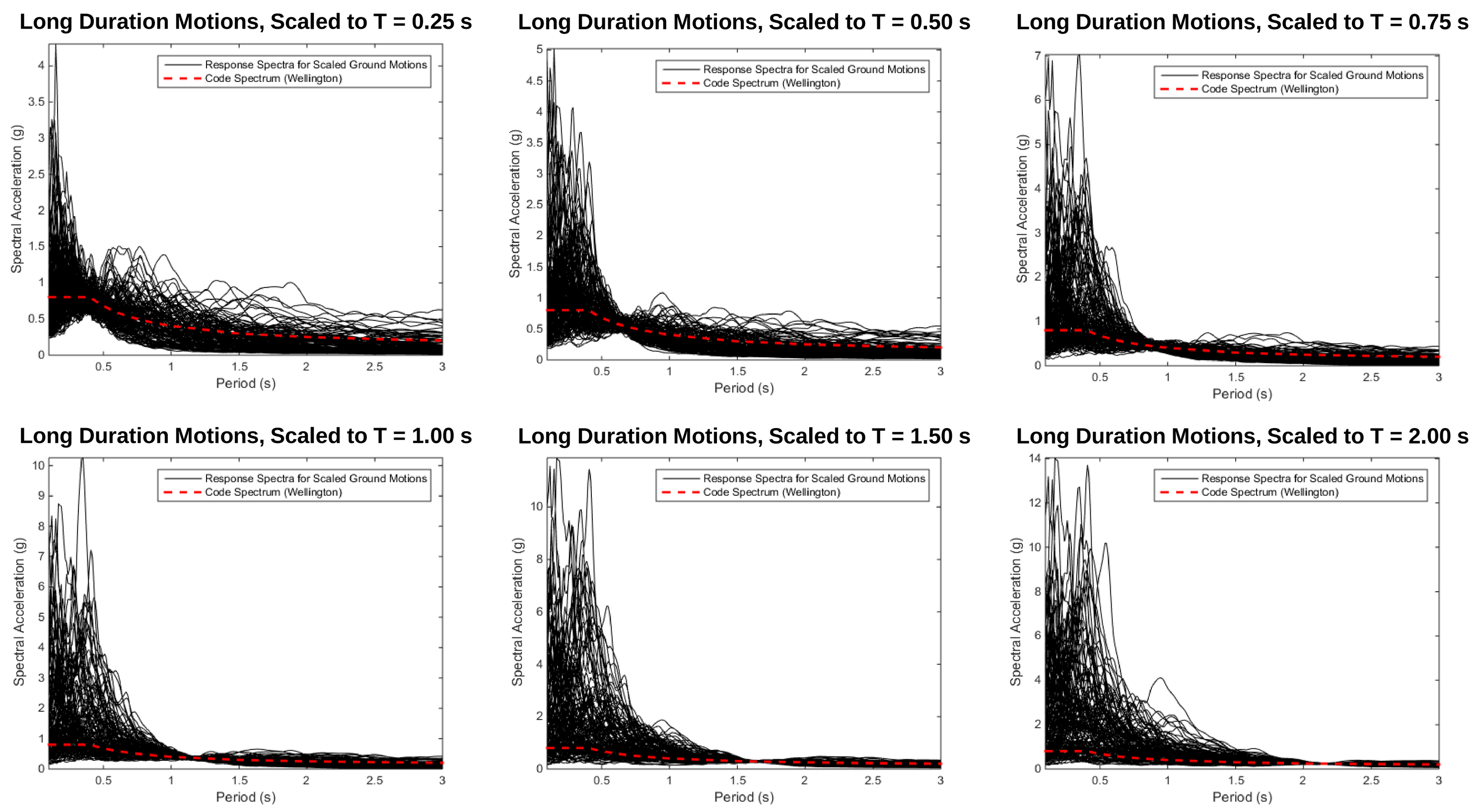
Despite the abundance of large-scale laboratory testing to assess the seismic performance of components and systems, there is a lack of consistency in the testing protocols being used, which creates challenges when comparing test results across experimental programs. A lack of consensus is evident in existing recommendations for uni-directional testing protocols, while guidance on bi-directional protocols is limited. In an effort to address these shortcomings, specific recommendations for loading protocols are being developed for structural components, with the first phase of this study focused on the development of uni-directional testing protocols. To accomplish this objective, a suite of ground motions, scaled to the New Zealand code spectra for Wellington (an urban center located in a region of high seismicity), were used to conduct nonlinear response history analyses for a suite of single degree of freedom (SDOF) systems that comprised a range of ductility factors and structural periods. Using these results, statistical distributions of cumulative damage parameters are being used to develop loading protocol recommendations. Much of the approach outlined in this poster follows the methodology used by Mergos and Beyer (2014) to develop loading protocols suitable for regions of lower seismicity than that considered here.

Selection and Scaling of Ground Motions:



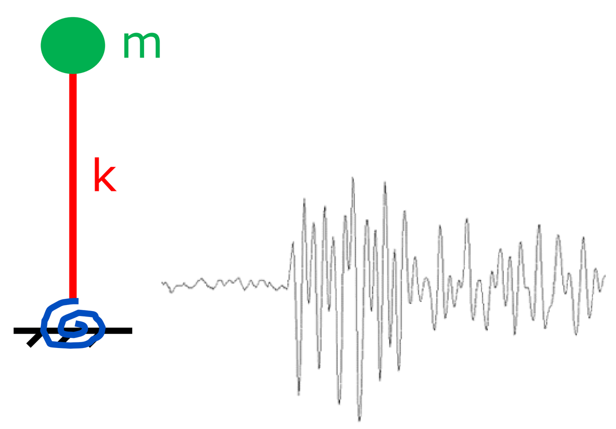


A set of both long duration and short duration ground motions, provided to the authors by Jack Baker (see Chandramohan et al, 2014) were analyzed separately to assess the impact of ground motion duration on the development of loading protocols. Each set of ground motions contained 146 motions, and each ground motion in one set had a matched pair in the other set such that the two motions produced very similar response spectra. A 1/500-year NZS 1170 spectrum (shown above) was developed for the Wellington Central Business District and was used to scale the response spectra (shown below for the long duration ground motion set) over the period range of interest, taken here as 1.0 and 1.3 times the fundamental period.



Nonlinear Single Degree of Freedom (SDOF) Analyses:

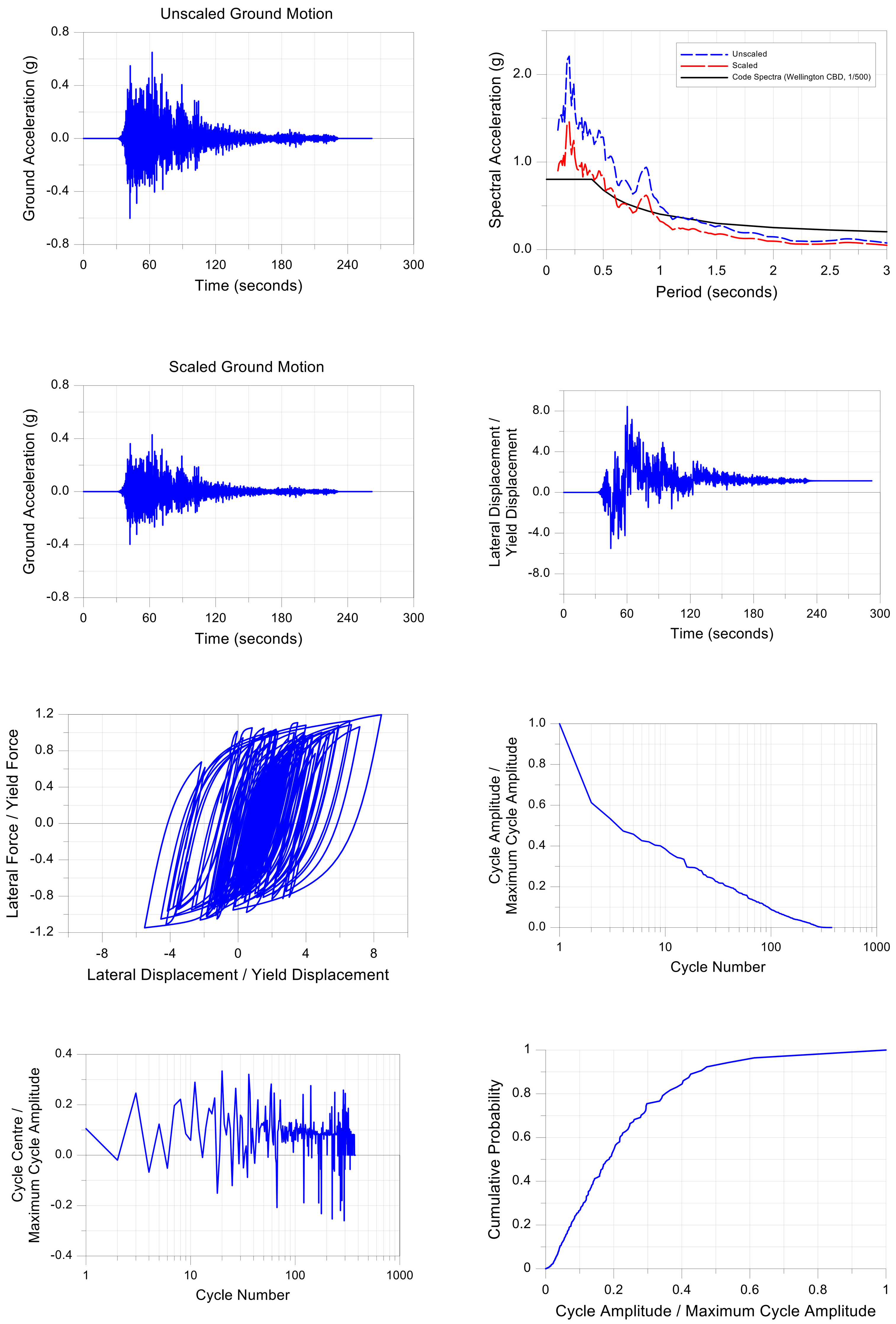
Nonlinear single degree of freedom (SDOF) analyses were conducted using OpenSees, with the hysteretic response modeled using Steel02 (other models will be considered in future studies). For each ground motion, SDOF analyses were conducted for a range of structural periods (0.25s, 0.5s, 0.75s, 1.0s, 1.5s, and 2.0s) and a range of ductility factors (1, 2, 4, and 6). The use of an SDOF system was intended to provide a reasonable representation of behaviour for structures without significant higher mode effects.



Results for Each SDOF Analysis:

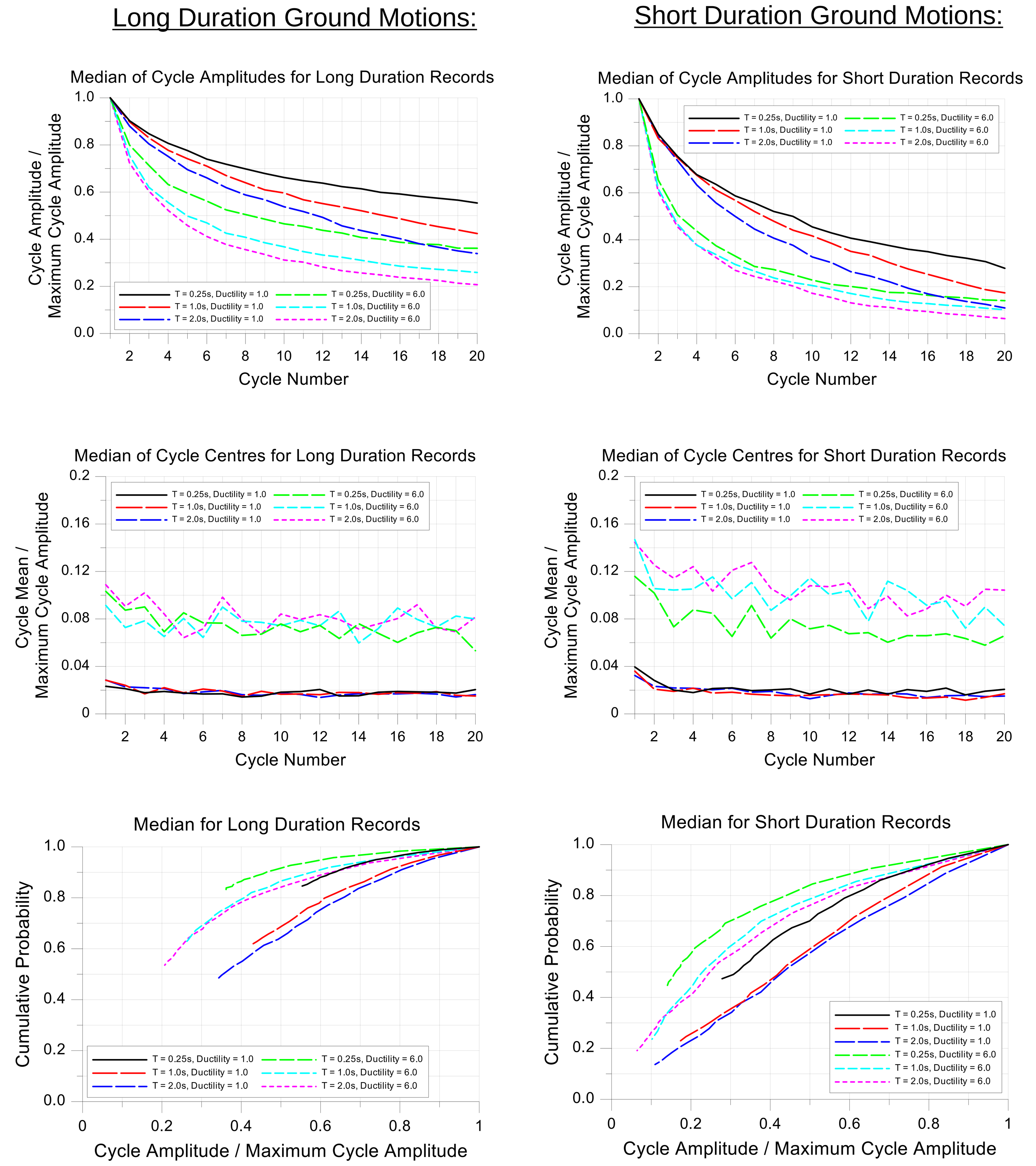
Sample results from a single SDOF analysis are shown below for a structure with a fundamental period of 1.0 second and a ductility factor of six subjected to the ground motion recorded in Concepcion during the 2010 Maule, Chile earthquake. The ground motion, which was scaled to the 1/500-year NZS 1170 spectra based on least squares regression over 1.0 to 1.3 times the fundamental period, generated the lateral displacement history and load deformation history shown below for the SDOF system. A rainflow cycle counting algorithm (consistent with that described by Dowing and Socie, 1982) was programmed in Matlab and was used to count the cycles in the deformation history. Rainflow counting produces closed (i.e., full) cycles but does not preserve the order of the peaks. The cycles were re-ordered from largest to smallest to produce the last three plots shown below. For this analysis, there are roughly 10 cycles larger than 40% of the peak cycle displacement, and the cycles are generally centred about zero.

Sample Results for T = 0.75 s, Ductility = 6.0 for Maule 2010 Earthquake recorded at Concepcion:



Statistical Results from SDOF Analyses:

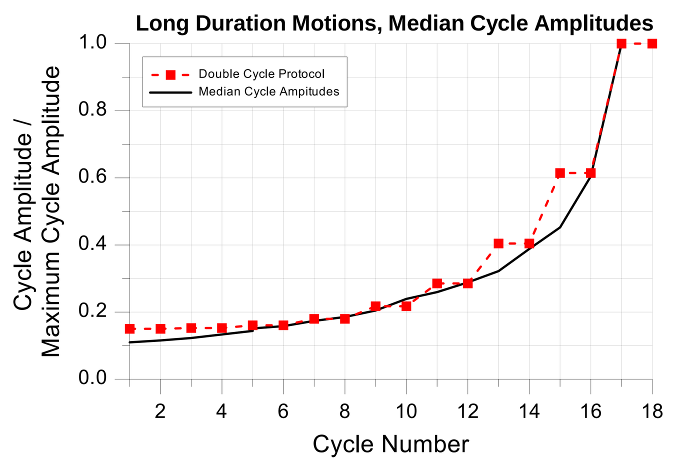
Statistics were carried out on results within both sets of ground motions (short and long duration). Results are sensitive to structural period, ductility level, and ground motion duration. More cycles at larger levels (relative to peak) are evident at shorter period, lower ductility, and longer duration.



Development of Loading Protocols:

Consistent with the approach used by Mergos and Beyer (2014), loading protocols may be developed by curve fitting a protocol to the history of normalized cyclic amplitudes, arranged in ascending order. For the sample plot shown at the right, median cycle amplitudes for the long duration ground motion set are considered. Mergos and Beyer (2014) recommend the following curve-fitting expression:

$$f(t) = \frac{1}{e-1} \cdot \left[\delta_o \cdot e - 1 + (1-\delta_o) \cdot \exp\left(t^{\alpha}\right)\right]$$



Future Studies:

This study is ongoing. The SDOF analyses will be expanded to include scaling of ground motions to various demand levels (i.e., not just 1/500-year) and use of various hysteretic models (i.e., with different levels of pinching). Loading protocols generated using the approach outlined in this study are valid for components that deform in a manner identical to the overall structure (e.g., a full-height shear wall). Loading protocols for specific structural components will be developed based on the relationship between component demands and the overall system demands that are obtained through the SDOF analyses. The methodology outlined in this poster does not take sequencing effects into consideration. Future studies will also focus on sequencing effects, in addition to the development of bi-direction loading protocols and the development of metrics to assess the reparability limit state.