VALIDATING SSI RESPONSE OF BUILDINGS ON LIQUEFIABLE DEPOSITS USING CENTRIFUGE TESTING AND NUMERICAL MODELLING

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Purpose of Research

The increasing shift towards performance based geotechnical earthquake engineering design requires an improved understanding of soil-structure interaction (SSI) for structures on liquefiable deposits. A number of numerical software and constitutive models are now available for users to assess and understand the above problem. While numerical modelling provides a low cost, time efficient alternative to physical model testing, it is important to understand the advantages and limitations of numerical simulations of physical processes.

The purpose of this research is to validate numerical models that consider soil structure interaction (SSI) response of buildings on liquefiable deposits against T4.6-40 centrifuge test that was undertaken as part of the NEESR Seismic Performance Assessment in Dense Urban Environments project. The goal of the research is to be able to identify the ability of numerical models to model physical mechanisms. The relative performance of two pairs of numerical software and constitutive soil models have been considered. For the research we have selected to validate numerical simulations developed using FLAC and the PM4Sand constitutive model and OpenSEES and the PDMY02 constitutive model.

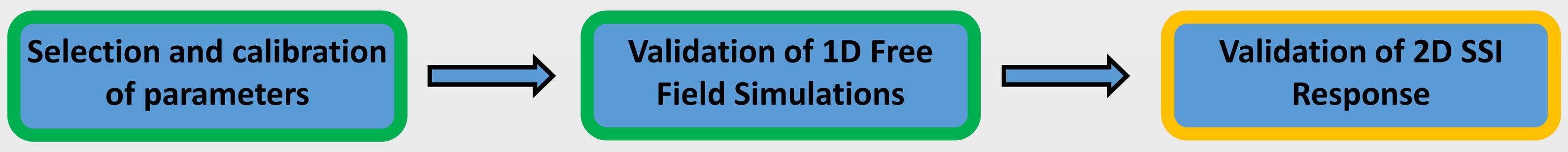


Figure 1: Stages of the research project (green – stages that have been completed; orange – research currently ongoing)

Centrifuge Testing

The T4.6-40 centrifuge test, undertaken by Hayden et al. (2014), has been used to validate the numerical models for this project. Centrifuge tests provide a set of well instrumented and well constrained data that can be compared against the results produced from the numerical simulations. A profile view of the centrifuge test layout that has been modelled is shown in Figure 2. The centrifuge test that is used for this project considers both the response of isolated structures and two adjacent structures. The current research only consider the response of isolated structures.

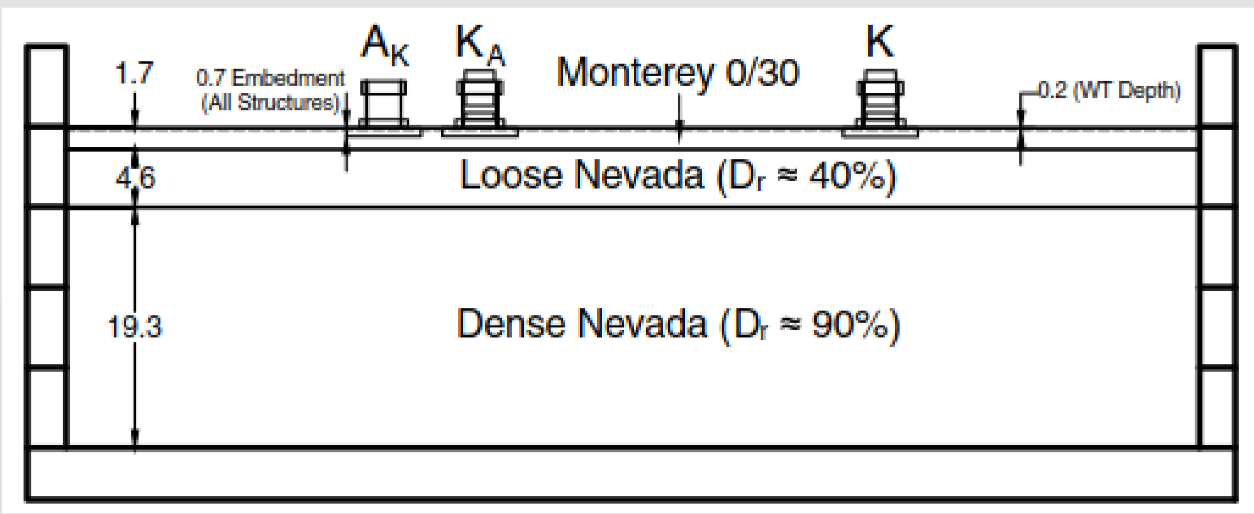


Figure 2: Profile view of T4.6-40 centrifuge test (Hayden et al., 2014).

PM4Sand and PDMY02 Parameters

PM4Sand and PDMY02 soil parameters have been approximated based on the calibration work undertaken by Armstrong and Boulanger (2015) and Karimi and Dashti (2016) respectively. Both of the above studies calibrated parameters for Nevada sand and Monterey sand for the purpose of validating numerical simulations against centrifuge measurements. It is the authors view that basing the parameters for this project on calibration work that has already undertaken provides numerous advantages. These include:

- Minimising the tendency to 'over fit' parameters to a limited number of centrifuge tests
- The influence of parameter calibration on results is minimised when comparing observations from this project against that made by the authors referenced above
- There is a limited amount of time available for the project. As such, the adopted approach saves time that can be directed towards other research tasks

Single element simulations of cyclic simple shear tests have been undertaken to compare the response of calibrated parameters to the default parameters suggested by the developers of PM4Sand and PDMY02. The single element simulations were also used to study the sensitivity of each of the parameters. The cyclic resistance ratio (CRR) for the calibrated parameters and the stress-strain response of loose Nevada sand under cyclic shear loading are shown in Figure 3a and 3b.

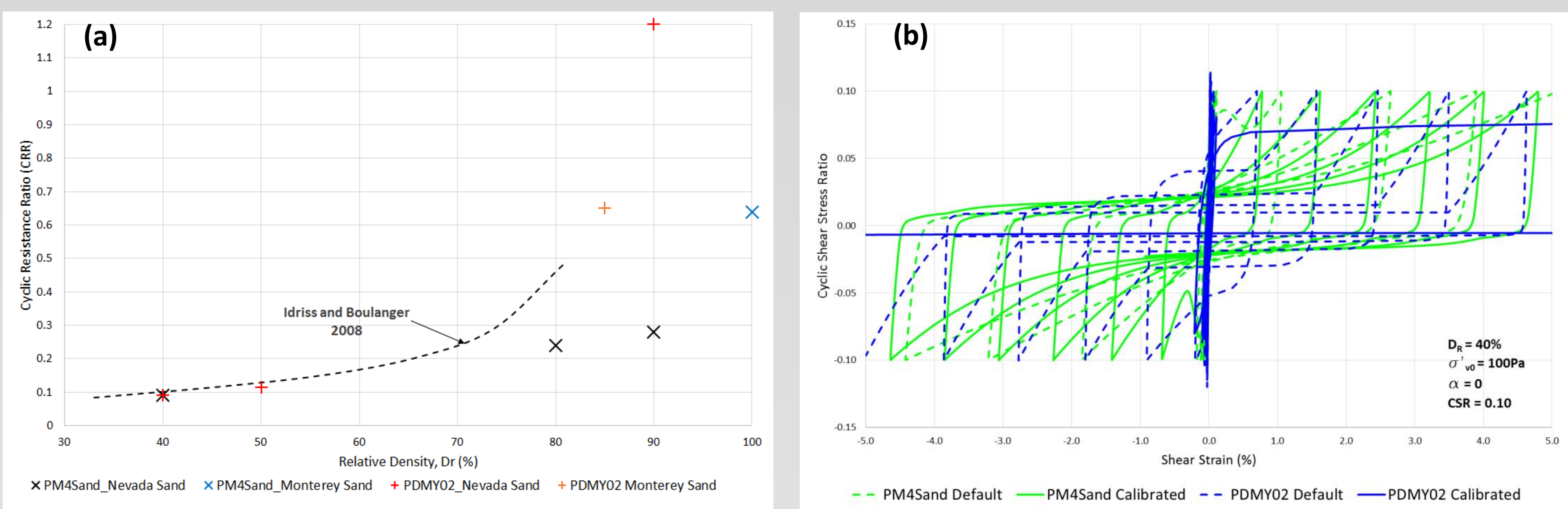
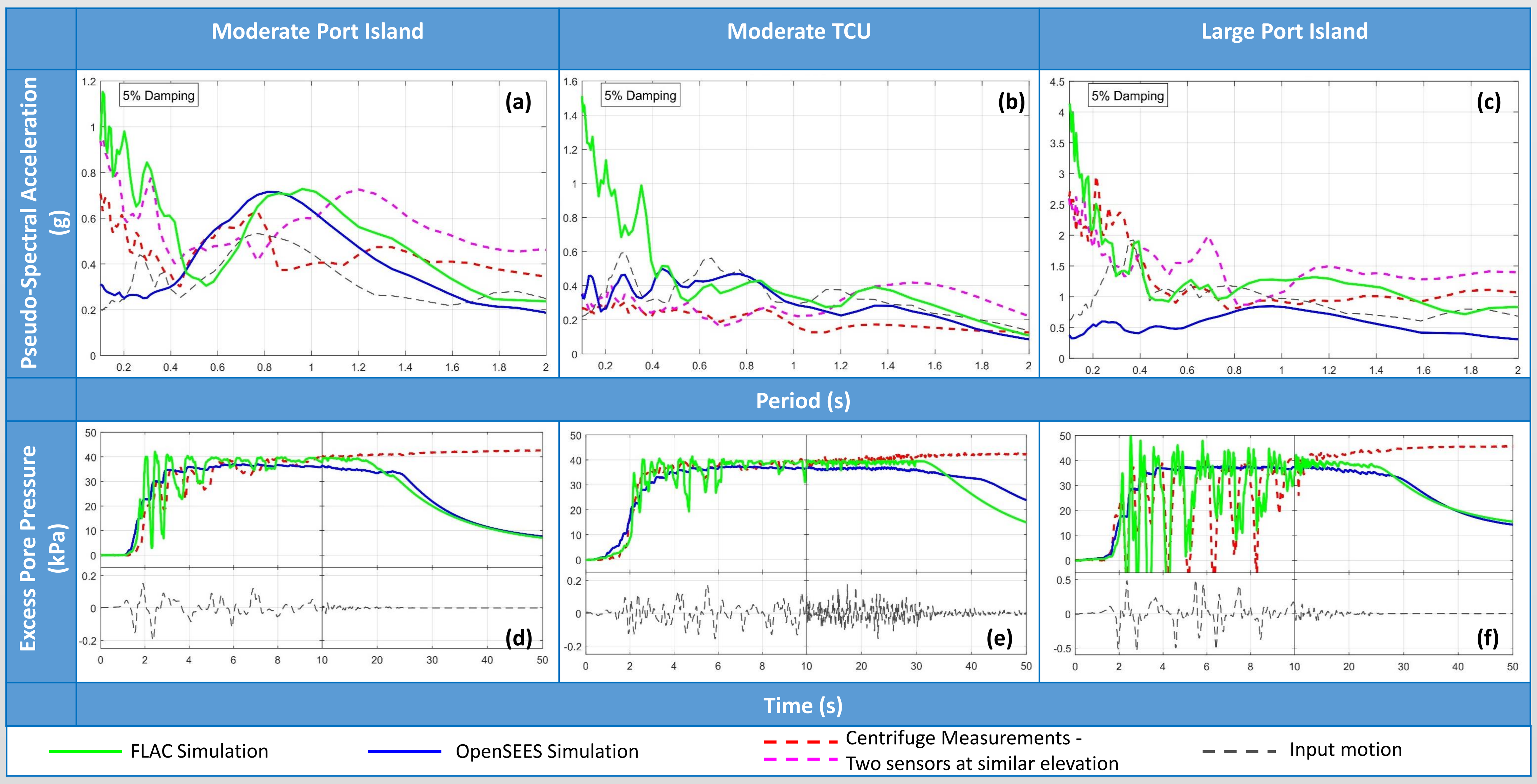


Figure 3: (a) CRR estimated for loose and dense Nevada sand and Monterey sand using calibrated parameters. (b) Stress-strain response of loose Nevada sand using default parameters suggested by the developers of the respective model and calibrated parameters.

1D Modelling Results

The numerical response of a 1D column of elements have been validated against the acceleration, pore pressure and displacement measurements recorded away from the structures (i.e. 'free field') in the centrifuge test. The acceleration and pore pressure response at the middle of the liquefiable layer for three of the ground motions considered (Moderate Port Island, Moderate TCU and Large Port Island) are presented in Figure 4. Broad observations from the 1D site response analysis are presented below. Note that reference to FLAC refers to the use of PM4Sand model with FLAC and reference to OpenSEES refers to the use of PDMY02 with OpenSEES.

- The simulated acceleration response in the dense Nevada sand matched well with the respective centrifuge measurements.
- Greater variability in the simulated acceleration response was however noted in the liquefiable layer and above. Generally a better agreement was noted between periods of 0.4 s and 2 s while significant variability was noted at periods shorter than 0.4 s as shown on Figures 4a, b and c.
- For the Large Port Island event, significant damping of the ground motion was noted in the OpenSEES model. For the high levels of shaking the results were found to be relatively sensitive to the set of parameters that has been considered.
- Both numerical models indicated pore pressure to dissipate more rapidly than that measured in the centrifuge tests (refer to Figures 4d, e and f). This is consistent with observations made by others in the literature.
- Significant dilation spikes were simulated in the FLAC model. Similar dilation spikes were noted in the centrifuge tests under pulse-like ground motions (Moderate and Large Port Island) as shown on Figure 4d and f.
- Vertical settlements were significantly underestimated by the numerical models providing a poor simulation of volumetric mechanisms. This is again consistent with observations made by other in the literature.



Figures 4a, b and c: Present a comparison of the simulated acceleration response in the soil column and the acceleration in the 'free field' of the centrifuge tests. Figures 4d, e and f: Present a comparison of the pore pressure response from the 1D simulation and centrifuge measurements

Current and Future Research

The validation of the 2D numerical model, comparing the ability of the models to simulate the complex interaction between the structure and soil is currently being undertaken using FLAC and PM4Sand.

Similar to the 1D validation work that has been completed, the acceleration, pore pressure and vertical settlements due to deviatoric and volumetric mechanism will be compared against the respective measurements from the centrifuge testing.

While not part of the scope for the current project, future research that can be undertaken based on the current work include:

- Validation of structure-soil-structure interaction (SSSI) of adjacent structures using the centrifuge test considered in this project.
- Consideration of the effect of bearing pressure and structural height on SSI and SSSI, such as the case where a small light building is located adjacent to a heavy, tall structure.

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