Seismic performance of adjacent mat-supported structures on liquefiable soil: validation of numerical model using centrifuge tests

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Research Purpose

Current design provisions assume the buildings to be away from other structures. However, in many cases like large cities, structures can be located close to one another. These adjacent structures can interact with each other through the underlying soil in a phenomenon known as structure-soil-structure interaction (SSSI). This interaction can alter the response of buildings during earthquakes and should be considered in structural design. The occurrence of liquefaction under the structures affects this interaction and changes the governing mechanisms. However, little is known about the interaction of nearby buildings especially when it is affected by soil liquefaction. The purpose of this research is to develop a numerical model to study SSSI on softened ground and validate it against two centrifuge tests performed by Hayden et al. (2014).

Centrifuge Tests Overview

- This study uses two geotechnical centrifuge test with layouts presented in Fig. 1 to validate the developed numerical model.
- The names of the tests (i.e. T4.6-40 and T4.5-50) contain two numbers which correspond to the height of the liquefiable layer in meters and its relative density (D_r), respectively.
- Each test include a layer of dense Nevada sand (D_r = 90%) at the bottom, a layer of loose Nevada sand (D_r = 40 or 50%) in the middle and a layer of dense Monterey sand (D_r = 85%) at the top.
- Three types of structures (i.e. Structure A, K and J) with properties shown in Table 1 are included in each tests along with about 140 data acquisition instruments. The subscript in the name of the structures if any, indicates the name of the adjacent structure.
- It is noteworthy that T4.6-40 also contains an AJ pair of structures which is not shown in Fig. 1.
- Four input motions are applied to the bottom of the centrifuge container to simulate the earthquake.

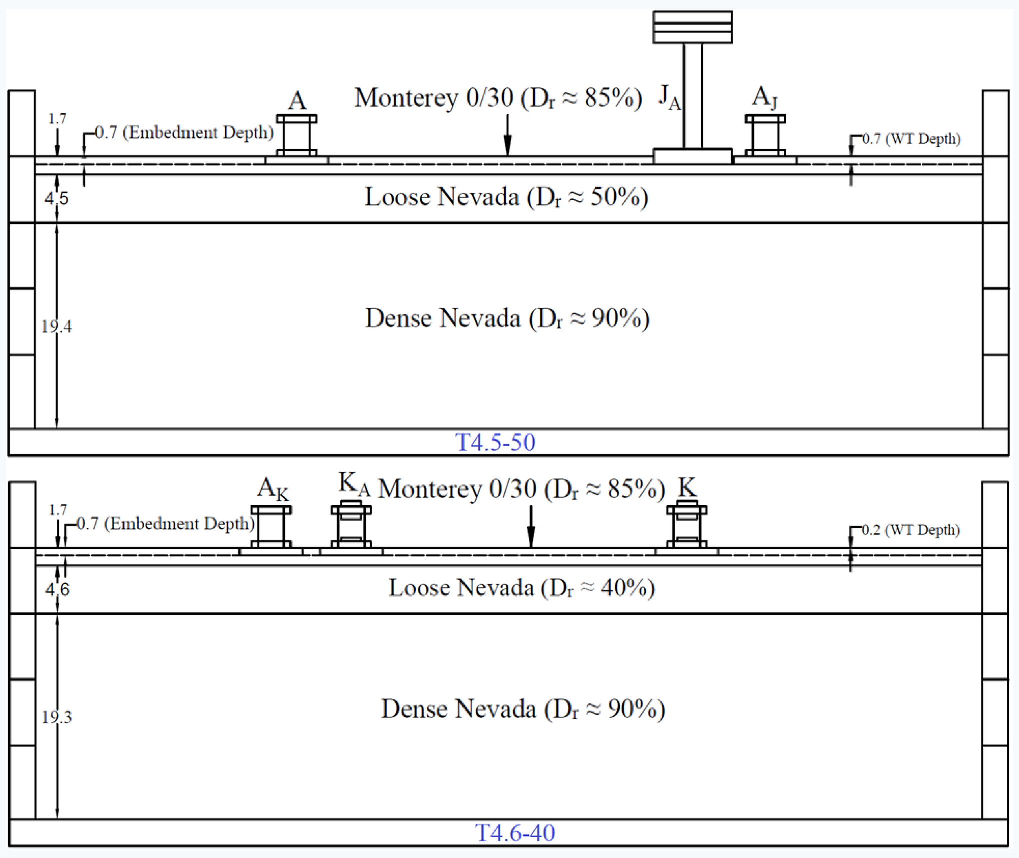

Fig. 1 – Profile view of the centrifuge tests (Hayden et al., 2014)

Table 1 – Properties of the structures used in the centrifuge tests

Structure	Bearing pressure (kPa)	Fixed-base period (s)	Deck center of mass (m)*
A	65	0.33	3.9
K	180	0.38	3.9
J	180	0.85	15

* Measured from bottom of the foundation

Numerical Model

- A fully coupled, plane-strain, dynamic finite difference (FD) analysis is performed using FLAC 8.0 software (Itasca Consulting Group 2016).
- PM4Sand constitutive model implemented in FLAC software by Boulanger and Ziotopoulou (2017) is utilized to capture the cyclic response of the saturated soil during the seismic events.
- PM4Sand parameters are calibrated for all soil layers used in the centrifuge tests.
- The maximum mesh size is determined using mesh sensitivity analysis. Fig. 2 illustrates an example of the developed models in FLAC. Furthermore,
- The properties of Monterey sand is used for the soil-foundation interface properties as the steel/aluminum foundations of the centrifuge tests are coated with this sand to simulate the rough interface between the soil and foundations.
- A 2% damping is calculated by analyzing the time history of free vibration tests performed on the structures and assigned to each structure in the model.

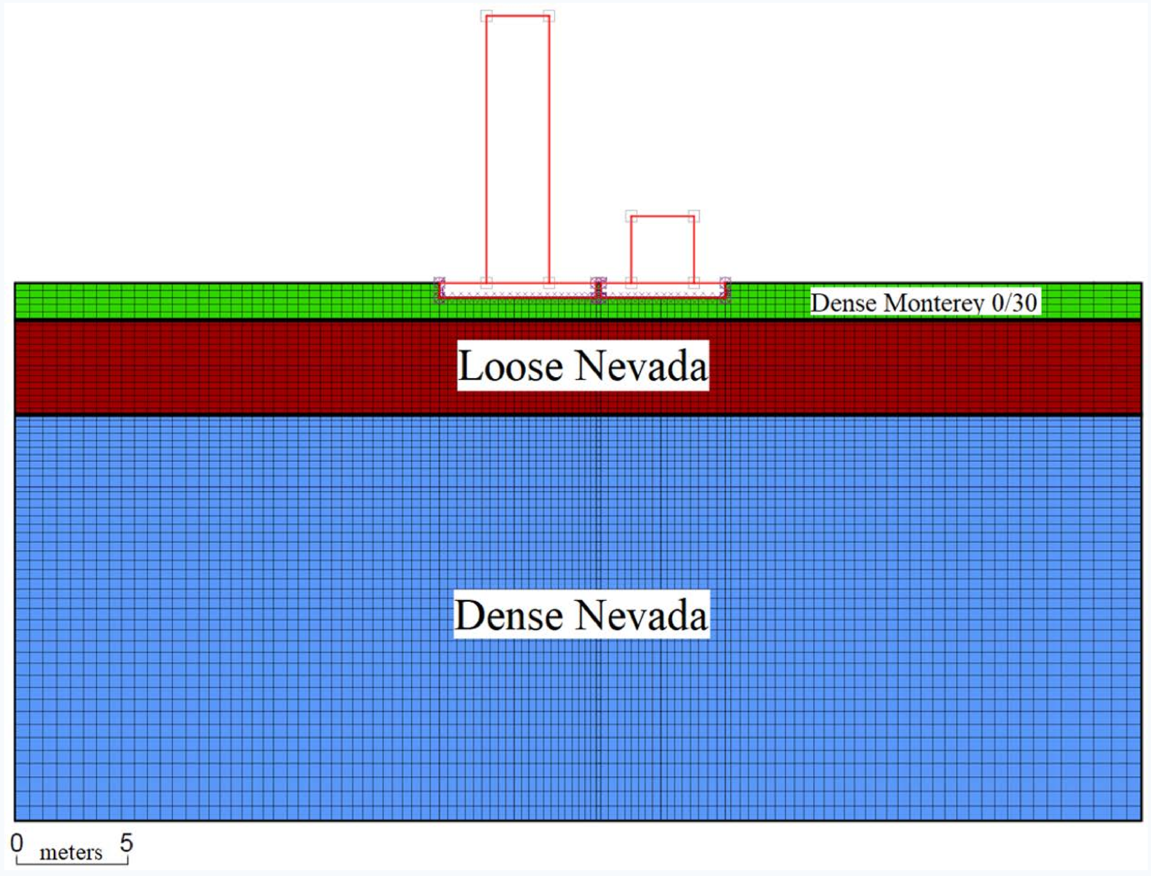

Fig. 2 – The developed FD model for simulating the interaction of AJ structures in T4.5-50

Soil Response

- Proper estimation of excess pore water pressure generation under the structures is vital for capturing the governing mechanisms of structure settlement and tilt.
- Fig. 3 shows that the numerical model is generally able to capture the generation of excess pore water pressure in the middle of the liquefiable layer under the structures. However, it generally overestimates the pore pressures under the heavier structure (i.e. Structure K and J) during the TCU motion. Additionally, it slightly overestimates the pore pressures between the structures during the large PRI motion.

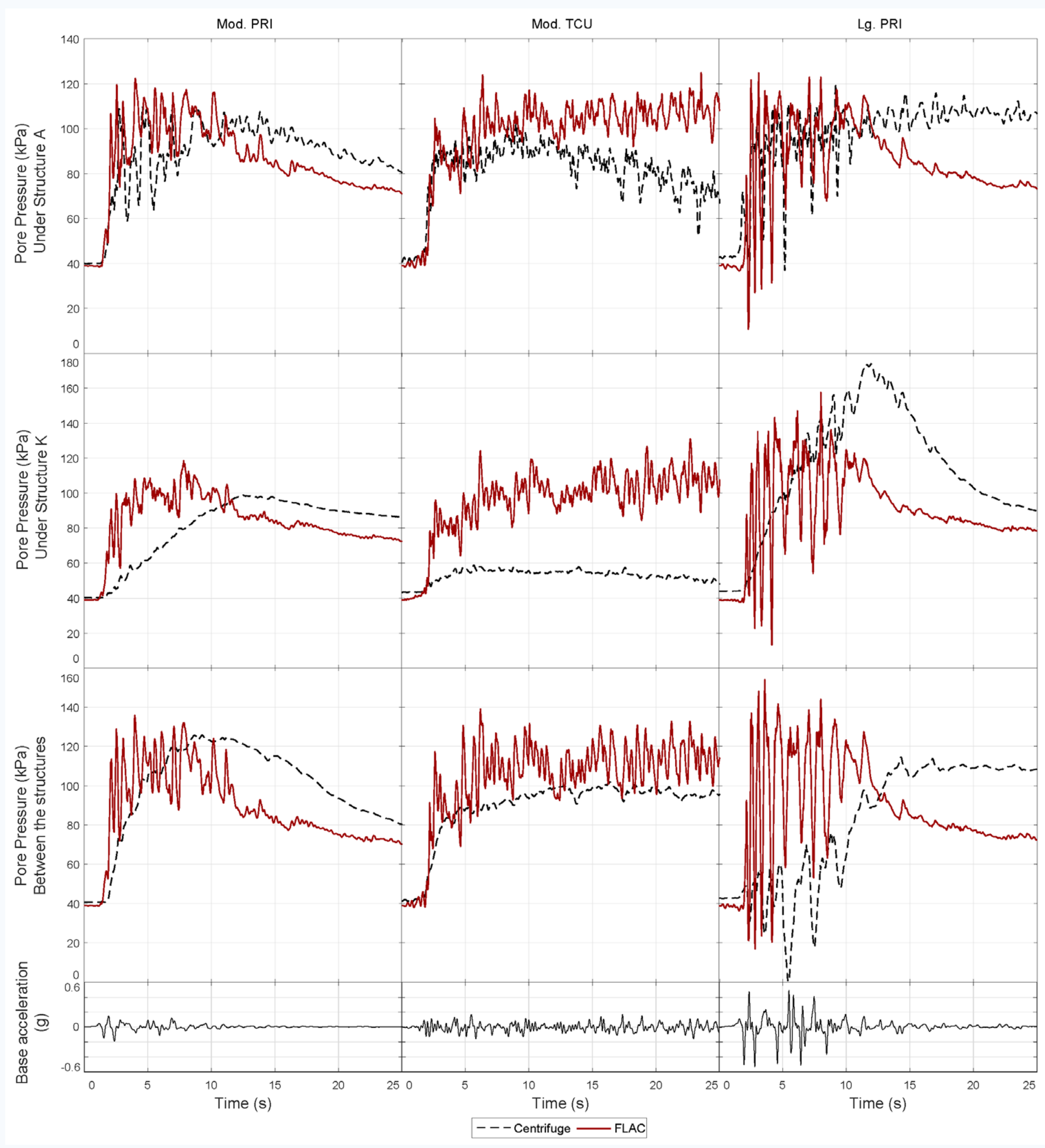

Fig. 3 – Estimation of excess pore pressures under AK structures

Building Response

- Settlement and tilt of the structures are the most important consequences of soil liquefaction which mainly depend on the generation of excess pore pressures under the buildings and can cause severe damage to the superstructures.
- Fig. 4 and Fig. 5 summarize the values of structure tilts and settlements estimated by FLAC compared to the experimental data. It is evident that the numerical model can estimate the settlements and tilts of the structures well.
- There are a few cases where the estimated building response does not match the experimental data which is mainly due to inaccurate estimation of pore pressures under or between the structures.
- Fig. 6 shows the effect of SSSI on the response of structures by normalizing settlements from Fig. 4 by the corresponding values of isolated structures resulted from soil-structure interaction (SSI).
- It is evident that in these two specific centrifuge tests, SSSI generally reduces the settlements of the structures. This trend is captured well by the developed numerical model. The numerical model also calculates the magnitude of this reduction well.

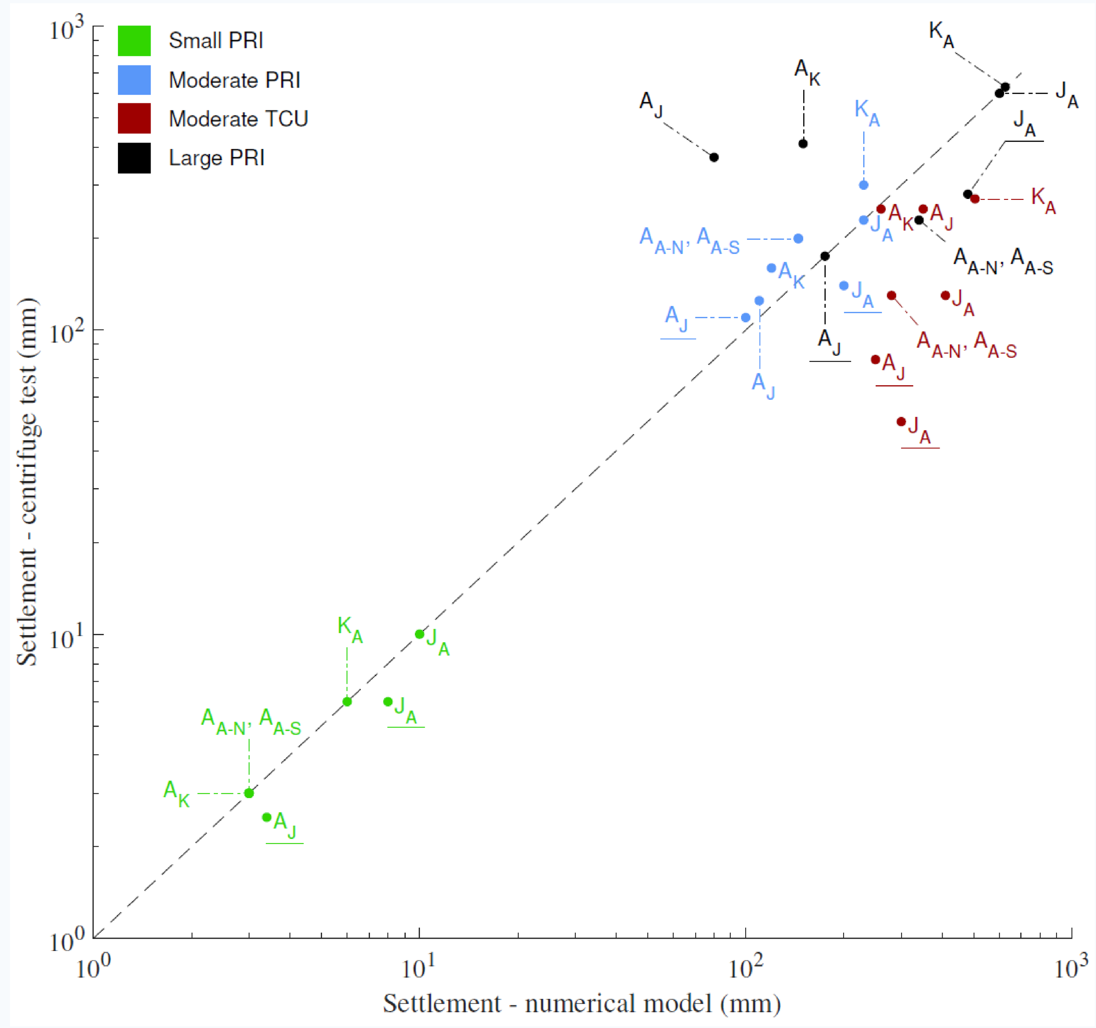

Fig. 4 – Estimated values of structure settlements compared to the experimental data

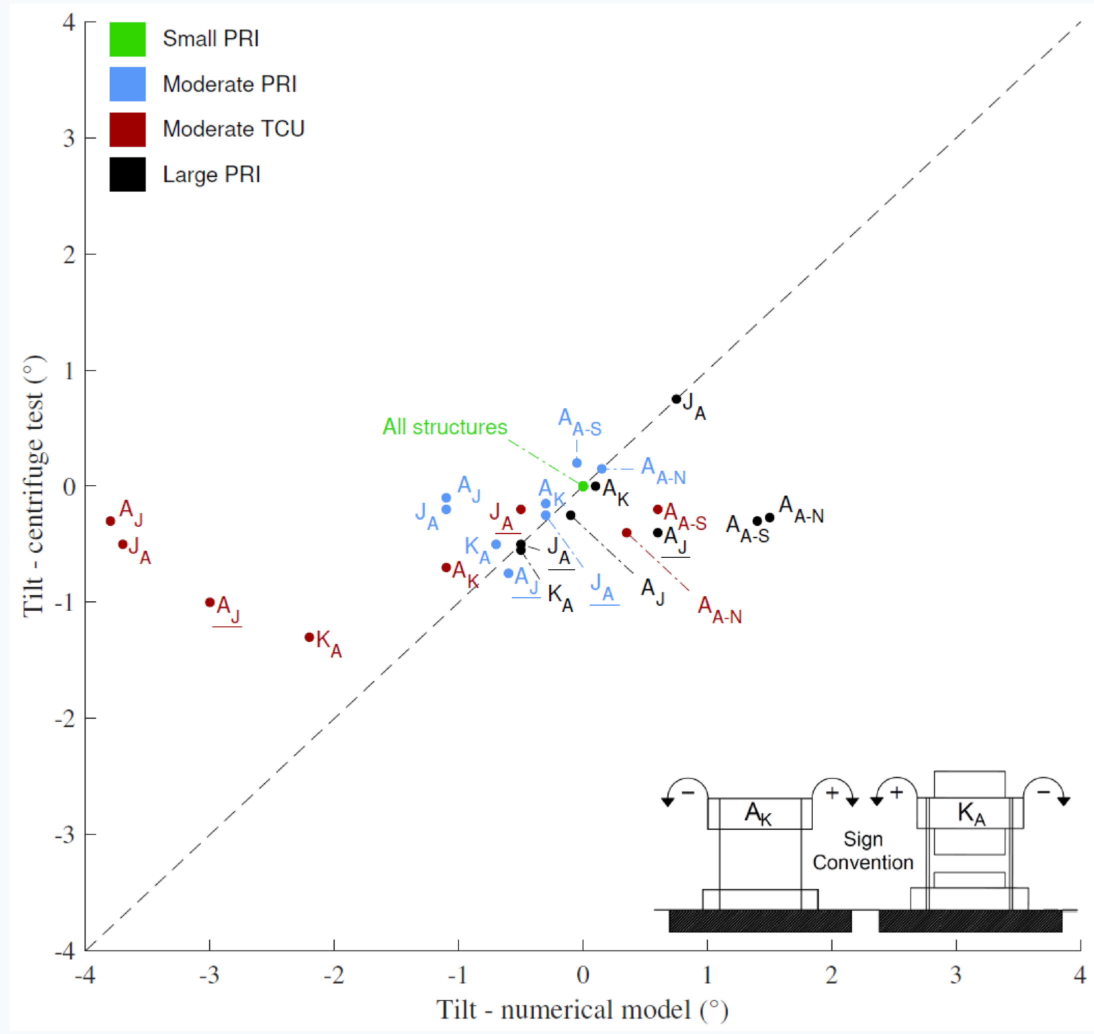

Fig. 5 – Estimated values of structure tilts compared to the experimental data

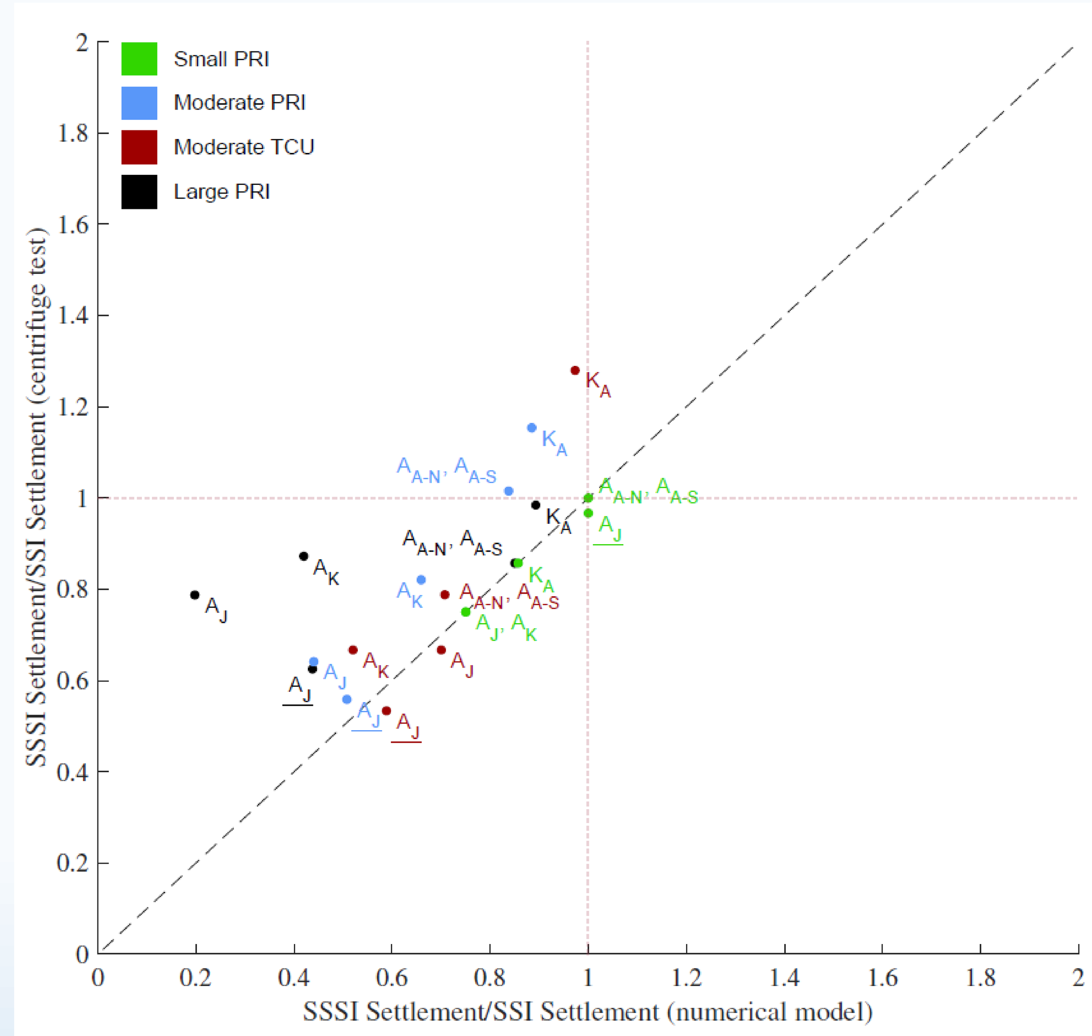

Fig. 6 – Effect of SSSI on structure settlements in the numerical model and centrifuge test

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