Wave propagation between adjacent structures

G. Barrios[1], Y. Lim[2] and N. Chouw[3]

1. Corresponding Author. PhD student, Department of Civil and Environmental Engineering, the University of Auckland, Auckland, New Zealand.
Email: gbar737@aucklanduni.ac.nz

2. Master Student, Department of Civil and Environmental Engineering, the University of Auckland, Auckland, New Zealand.
Email: ylim069@aucklanduni.ac.nz

3. Associate Professor, Department of Civil and Environmental Engineering, the University of Auckland, Auckland, New Zealand.
Email: n.chouw737@auckland.ac.nz

Abstract

The influence of adjacent structures has been studied mainly considering closely adjacent structures. This assumption intended to maximise the possible effects of a neighbouring structure. In this paper results from tests on two structures located at a large distance using a laminar box filled with sand are presented. The structural models were located at a distance of four times the footing width. An impact load was applied to the top and footing of one of the models. The wave propagation from the impacted model to the adjacent structure via the common soil was investigated. Measurements beneath the sand surface at both footings location and in the mid-distance between them were performed. Acceleration was also recorded at the footing as well as top of both models. The results show that even with this relatively large distance, a substantial energy was still transferred to the adjacent structure. The influence of the frequency of the models was also addressed.

Keywords: adjacent structures, neighbour structure influence, wave propagation

1 INTRODUCTION

The difference in the response of closely adjacent structures compared to the stand-alone condition has been studied since Luco and Contesse (1973) proposed the Structure-Soil-Structure Interaction (SSSI) term to refer to this interaction. The research available nowadays has focused on closely adjacent structures. The short distance between models intended to maximize the interaction effects. However, from the authors' best knowledge, the influence of the distance between the structures has not been addressed.

Most of the SSSI works available have considered either a numerical approach or the use of a geotechnical centrifuge. Despite the valuable contributions presented using these approaches, they commonly have geometrical limitations (or computational capacity limitations in the case of numerical modelling) that did not allow to study models at a large distance.

Ghosh and Madabhushi (2007) validates the results of geotechnical centrifuge tests comparing them with standard formulae presented in different codes commonly use to evaluate soil-structure interaction. Knappett et al. (2015) studied the interaction between two models using a geotechnical centrifuge. The tests results emphasise the complexity of SSSI showing reduction or increment of the co-seismic settlement depending on the properties of the adjacent structures. Trombetta et al. (2013; 2014) presented results from a centrifuge test on nonlinear models. Conclusions of this study emphasized the relevance of the energy dissipation processes. When nonlinear response of the structures was observed, a lower influence of the adjacent structures was measured.

Numerical models have been crucial to study complex geotechnical problems such as SSSI. However, numerical results must be validated using either site observations or proper laboratory results. Aldaikh et al. (2016) presented results from laboratory tests and numerical analyses considering two and three adjacent models. However, the authors used a foam block as the foundation soil, therefore the soil response was exclusively elastic. The models were located closely adjacent also to emphasize the interaction effects.

The use of large sol containers and a 1g shake table is another way to study geotechnical problems. These facilities allow studying a large number of models and a larger number of configurations due to the lower cost and, less geometrical restrictions compared to centrifuge test. Ge et al. (2016) studied five closely adjacent models on top of a large circular flexible soil container. The influence of the adjacent models on the response of the central model was studied. However, the response of an adjacent model was only compared to the response of the model surrounded by other four identical ones. The influence of the distance between them was not addressed.

The presented research study the interaction of single-degree-of-freedom (SDOF) models via the common soil. Models were placed at four times the footing width in order to address the influence of the distance between them. Three SDOF models considering different natural frequencies were studied. Models were tested in pairs on top of a big laminar soil container. The acceleration was recorded inside the soil beneath the footing and in the mid-distance between them. Acceleration was also measured at the footing and top of the models. A small impact load was applied at the footing (two perpendicular direction) and the top (only one direction) of each model. Curves showing the reduction on the maximum acceleration recorded are presented.

2 METHODOLOGY

A total of three SDOF models were studied. All models were built using a steel column 50 mm width and 5 mm thick. A total weigh of 275 N was placed on top of every model. A 200 mm x 200 mm steal plate 25 mm thick was used as the models base. Models M1, M2 and M3 have a height of 600 mm, 450 mm and 350 mm respectively. Properties of the models are presented in Table 1.

Table 1. Models properties

Model	Height (m)	Frequency (Hz)
M1	0.60	1.54
M2	0.45	2.29
M3	0.35	3.79

Models were tested in pairs on top of a large laminar box with 2 m x 2 m of cross-section and 1.5 m height. The box was filed with Waikato river sand. The sand density was 1.57 kg/cm3 (Dr=51%). The shear wave velocity (V_S) was measured before the and at the end of the tests obtained values of 147 m/s and 151 m/s respectively. The small change in V_S reflect a stable soil condition through all the tests. The first tests considered models M1 and M2 and the second tests models M2 and M3. A schematic of the tests is presented in Figure 1. An example of the acceleration thought the foundation soil is also presented. (a) Shows the acceleration in the impacted footing, a typical free vibration response can be observed; (b) shows the acceleration beneath the impacted footing, the acceleration is reduce but the shape keeps quite similar compared to (a); (c) shows the acceleration at mid-distance between footings, at this stage the frequency content of the wave have considerably changed; (d) shows the acceleration beneath the adjacent footing; finally (e) shows an amplification compared to the register from point (d).

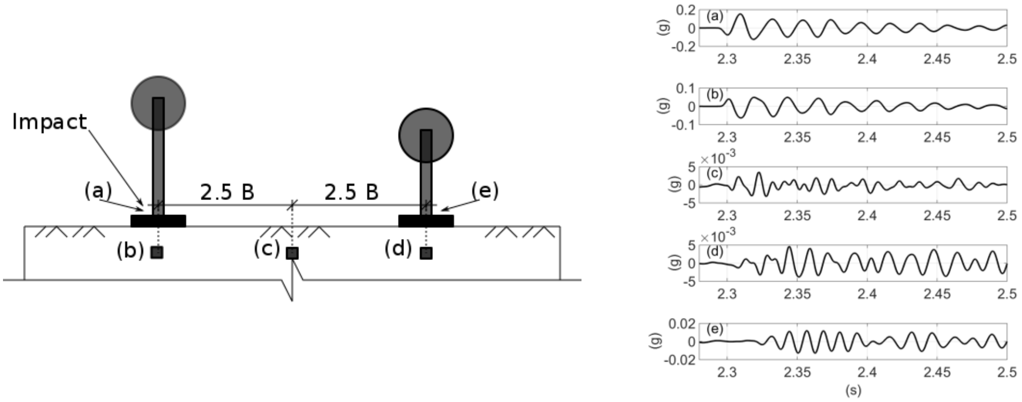


Figure 1. Wave propagation through the soil

An impact load using a steel hammer was applied at three different locations. The base of the model was impacted in two perpendicular directions, E-W corresponding to the direction where the adjacent model is located; and N-S direction (perpendicular to the location of the adjacent model). The top of the models were also impacted only in the N-S direction (see Figure 2). Every impact tests was performed three times. Results presented corresponds to the average of the three impacts except otherwise is stated.

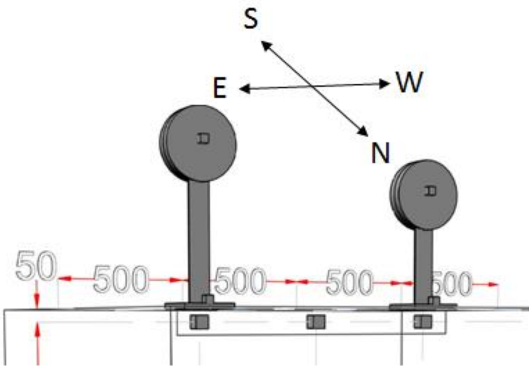
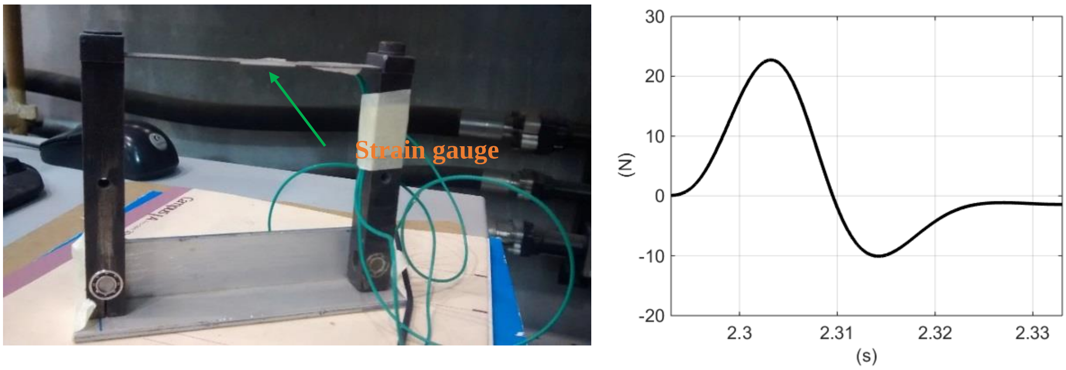


Figure 2. Schematic of the test

The impact load was measured using an impact device (Figure 3). The device used a flexible aluminium plate attached to two rigid legs. The force was applied directly to the aluminium plate where a strain gauge was located.



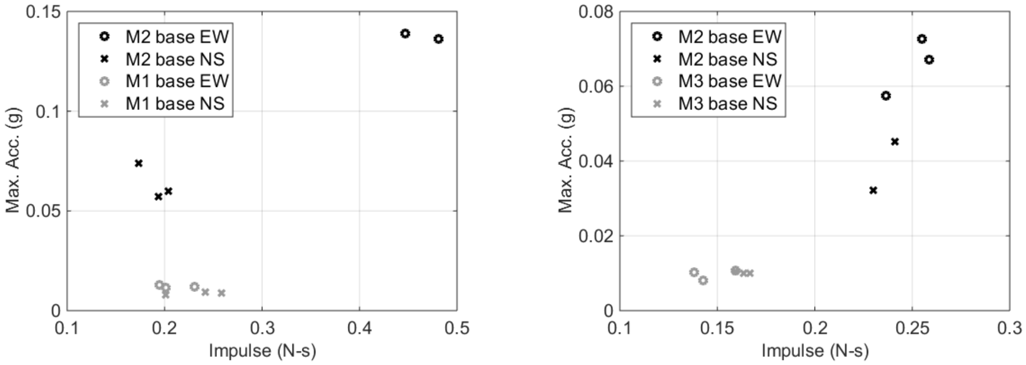
a. Impact device

b. Impact force

Figure 3. Impact device and measured force

3 RESULTS

The maximum acceleration recorded at the base of model M2 is shown in Figure 4. Figure 4-a shows the results for tests considering models M1 and M2. Figure 4-b shows the results for test M2-M3. In both figures results from impacts at model M2 are presented in black and in grey are the results when the impact was applied to the other model (M1 or M3). The acceleration is presented in terms of the impulse apply due to the impact load. The maximum acceleration recorded at M2 and the adjacent model (M1 for Figure 4-a, and M3 for Figure 4-b) are presented in black and grey respectively. As it was expected, when the footing of model M2 was hit, the larger the impulse, the larger acceleration recorded. However, when the impact was applied at the adjacent model the maximum acceleration was almost constant regardless the applied impulse. This phenomenon may be explained by the filtering of the signal through the soil.



a. Test M1-M2

b. Test M2-M3

Figure 4. Maximum acceleration recorded at model M2 for impact at both models

The fast Fourier transform (FFT) of the acceleration recorded at both footing when footing M1 was hit is presented in Figure 5. The FFT of the impacted model (M1) presented two clear peaks close to 0.5 Hz and 16 Hz. Both peaks are considerable reduced in the acceleration recorded at footing M2 (after the wave has travelled through the soil). This reduction support the low influence of the impact magnitude of the acceleration on model M2 when the adjacent model was impacted. The low and high frequency peaks are related to the vibration of the model and the vibration of the steal base plate respectively.

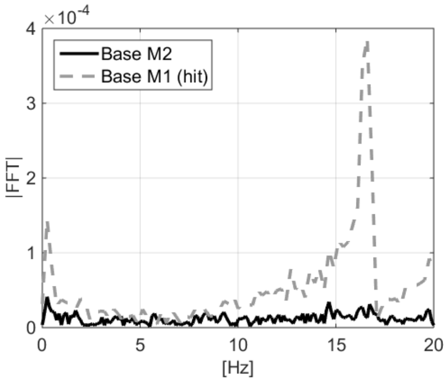
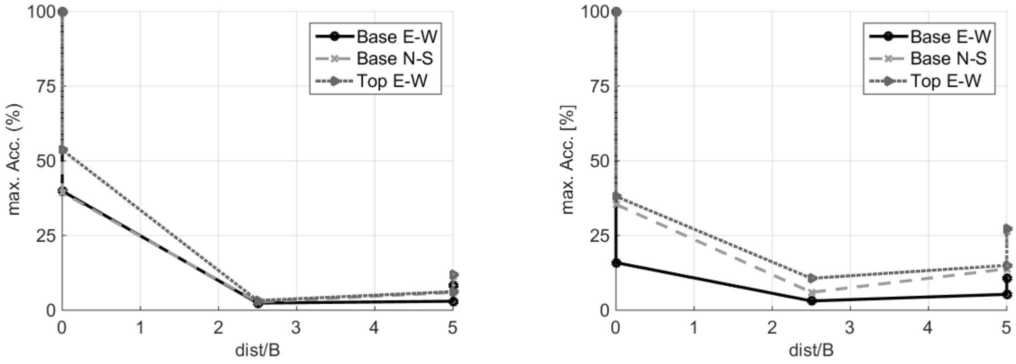


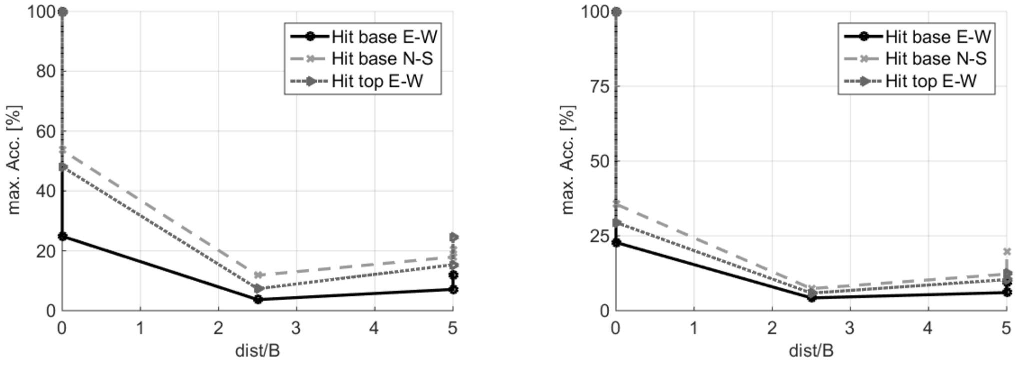
Figure 5. FFT of the acceleration at base M1 and M2 when base M1 was hit in E-W direction

The reduction of the acceleration from the impacted footing to the adjacent one is presented in Figure 6. The maximum acceleration recorded at every location was normalized by the maximum recorded at the impacted footing. The left-hand side of the graphs starts at 100% (corresponding to the maximum acceleration at the impacted footing), the other value at $dist/B = 0$, beneath the 100%, corresponds to the record beneath the impacted footing. The following point was recorded at the mid-distance between footings. Finally, the right-hand side of the graph shows the record beneath and the on top of the adjacent footing.



a. Acceleration at M2 when M1 was hit

b. Acceleration at M1 when M2 was hit



c. Acceleration at M2 when M3 was hit

d. Acceleration at M3 when M2 was hit

Figure 6. Normalized maximum acceleration through the soil and at both footings

All the curves presented a reduction close the 50% from the structure to the soil beneath the footing. In the mid-distance, a value close to 15% was observed across all the tests. However, there was almost no reduction from the mid-distance to the adjacent footing. Finally, the acceleration recorded at the adjacent footing presented an amplification compared to the value recorded in the soil underneath it.

The influence of the frequency of the impacted model can be addressed comparing Figure 6-a and Figure 6-c. When model M1 was hit (high frequency model) all the curves are relatively lower (Figure 6-a) than the case when M3 (low frequency model) was hit (Figure 6-c). The acceleration recorded at M2 just reach 12% of the original acceleration when M1 was hit and close to 20% when M3 was hit.

4 CONCLUSIONS

The presented research intended to study the influence of structures located a large distance. The study considered the response of single-degree-of-freedom (SDOF) models located at a distance of four times the footing width on top of a large laminar box. An impact load was applied to the models and the acceleration on the models and though the soil was measured.

As it was expected, the larger the impact applied to a given footing, the larger the acceleration recorded on it. However, when low influence of the magnitude of the impact was observed in the acceleration recorded at the adjacent footing (located at four times the footing width).

Curves showing the attenuation of the maximum acceleration through the soil were presented. This curves showed a considerable reduction immediately underneath the impacted footing. The reduction was lower up to the mid-distance between the footings. Finally, the maximum acceleration remained almost constant from the mid-distance point to the adjacent footing. An amplification of the acceleration on the adjacent footing compared to the one recorded beneath it was observed. This amplification may be related to the high contrast in between the soil and the footing stiffness.

Considering this large distance, a total of 15% to 20% of the acceleration at the impacted footing was observed in the adjacent model. This values can considerably change the response of a system if the interaction is considered. These results are expected to be a first experimental insight into the importance of adjacent structures even located at a large distance.

REFERENCES

Aldaikh, , Alexander, A, Ibraim, & Knappett, J 2016, 'Shake table testing of the dynamic interaction between two and three adjacent buildings (SSSI)', *Soil Dynamics and Earthquake Engineering*, vol 89, pp. 219-232.

Aldaikh, , Alexander, , Ibraim, & Oddbjornsson, O 2015, 'Two dimensional numerical and experimental models for the study of structure-soil-structure interaction involving three buildings', *Computers & Structures*, vol 150, pp. 79-91.

Dutta, , Bhattacharya, & Roy, R 2004, 'Response of low-rise buildings under seismic ground excitation incorporating soil-structure interaction', *Soil Dynamics and Earthquake Engineering*, vol 24, no. 12, pp. 893-914.

Ge, , Xiong, , Zhang, & Chen, J 2016, 'Shaking table test of dynamic interaction of soil-high-rise buildings', *European Journal of Environmental and Civil Engineering*, pp. 1-23.

Ghosh, B & Madabhushi, S 2007, 'Centrifuge modelling of seismic soil structure interaction effects', *Nuclear Engineering and Design*, vol 237, no. 8, pp. 887-896.

Knappett, JA, Madden, P & Caucis, K 2015, 'Seismic structure-soil-structure interaction between pairs of adjacent building structures', *Geotechnique*, vol 65, no. 5, pp. 429-441.

Luco, J & Contesse, L 1973, 'Dynamic structure-soil-structure interaction', *Bulletin of the Seismological Society of America*, vol 63, no. 4, pp. 1289-1303.

Trombetta, W, Benjamin , MH, Hutchinson, C, Zupan, D, Bray, D & Kutter, L 2014, 'Nonlinear soil-foundation-structure and structure-soil-structure interaction: engineering demands', *Journal of Structural Engineering*, vol 141, no. 7, p. 04014177.

Trombetta, W, Mason, H, Hutchinson, C, Zupan, D, Bray, D & Kutter, L 2013, 'Nonlinear soil--foundation--structure and structure-soil-structure interaction: centrifuge test observations', *Journal of Geotechnical and Geoenvironmental Engineering*, vol 140, no. 5, p. 04013057.