Contest 2015

Title: Coupled soil-foundation-structure systems earthquake response

Leader: Assoc. Prof. Nawawi Chouw
Co-investigators: Assoc. Prof. Rolando Orense,
Dr Tam Larkin
Prof. Michael Pender
Organisation: The University of Auckland
Total funding (GST ex): $297,500

Title: Coupled soil-foundation-structure systems earthquake response

Programme Leader: Associate Professor Nawawi Chouw

Affiliation: The University of Auckland

Has this report been peer reviewed? No

Table of Contents:

Key message for media:
In conventional engineering practice, the seismic design of New Zealand's buildings and bridges rarely considers the influence of the supporting ground. New research by the University of Auckland, incorporating observations from past earthquakes and laboratory experiments, shows that the ground plays a significant role in the intensity of seismic shaking. During earthquakes, neighbouring buildings have been found to significantly affect the intensity of shaking of all buildings, even in the case where subsoil liquefaction occurs. This finding is significant for New Zealand, since many of the cities and towns are built on weak soil close to rivers, lakes and the ocean. Our research now enables civil engineers to incorporate some of these findings into our building constructions.

Abstract:
In conventional design practice earthquake-induced soil-foundation-structure interaction (SFSI) is hardly ever considered. If SFSI is considered at all, then usually linear soil behaviour is assumed. The influence of adjacent structures on the nonlinear seismic behaviour of a group of soil-foundation-structure systems is always ignored. Yet, the significant impact of nonlinear soil behaviour on the overall structural seismic performance is observable, particularly in regions with poor soil, as seen in almost all major earthquakes. These deficiencies are addressed in this research. A clear understanding of the whole system dynamics will lead to more realistic, and thus economic, resilient aseismic design of future cities. The research outcomes will assist the Department of Building and Housing in developing detailed guidelines for shallow foundations to minimise damage under seismic loading.
A holistic consideration of the whole group of structure-footing-subsoil systems is a suitable response to the Royal Commission's request for a better understanding of the reasons for variability of ground movement.

Keywords: Seismic design, soil-structure interaction, structure-soil-adjacent structure interaction, liquefiable soil effect, shallow foundation

Introduction / Background:

The relevant background to the research outputs has been thoroughly described in the research proposal. However, the selected references below have been included here to provide a concise description of prior and concurrent research in this field.

A holistic consideration of a whole group of structure-footing-subsoil systems in the research allows an answer to the Royal Commission's request for a better understanding of the reasons for variability of ground movement to be formulated.

Thus this research has led to an understanding of the behaviour of nonlinear nonliquefiable and liquefiable soil at a scale unachievable by prior laboratory tests. The work includes an understanding of the seismic response of footings and structures, utilising a holistic approach to the soil-footing-structure system including neighbouring structures. The integrated approach considers the whole structure, footing, surrounding soil and structure-footing-soil-adjacent structure interaction.

The shake table and centrifuge tests have been accompanied by numerical analyses to better understand the relationship between the soil behaviour, the characteristics of the ground motion and the soil-footing-structure system. To incorporate relevant conditions, as reflected in the seismology of New Zealand, the project has focused on near-fault ground motions recorded in the recent Canterbury earthquake sequence.

As scheduled from 1st of April to 29th of June 2016, a series of centrifuge experiments have been performed at the National Institute for Occupational Safety and Health, Japan (J-NIOSH) in collaboration with colleagues in Tokyo. These experiments successfully investigated the behaviour of closely adjacent structures on liquefied soil. The centrifuge experiments were accompanied by companion large laminar box experiments on a shake table in the University of Auckland.

Impact Statement 1

This research will lead to improved earthquake resilience of New Zealand cities to ensure greater safety at a lower cost. To do this, we will develop recommendations on the seismic design of multiple interacting structure-foundation footing systems, incorporating the common surrounding soil. The outcomes of the research will become embedded in university teaching programmes for development of current and future engineers. For engineers already working within the industry, we will publish in relevant industry journals, run seminars and provide recommendations for improved aseismic design of buildings. These will enable the design of improved footing/structure systems and directly addresses gaps identified in the report of the Royal Commission of Inquiry into the Canterbury earthquakes.

❖ 1.1 Research Aim

Title: Understanding the soil liquefaction process and its effect on multiple footing response

Budget: $148,750

Research Aim achieved? Yes

This research aim will lead to an understanding of the free-field subsurface process of liquefaction. This will be further developed to include identification of the interaction between a single footing and the process of liquefaction. Having considered a single footing, the more realistic situation of a system of coupled footings with a common supporting soil medium will be investigated. This will reveal the complex relationship between earthquake characteristics and the response of coupled footings and subsoil.

Discussion

The experiments were performed using a large laminar box capable of simulating a close approximation to earthquake-induced sand movement in the excitation direction of the shake table at the University of Auckland (see Figure 1.1).

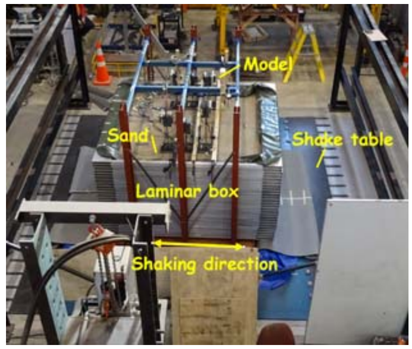
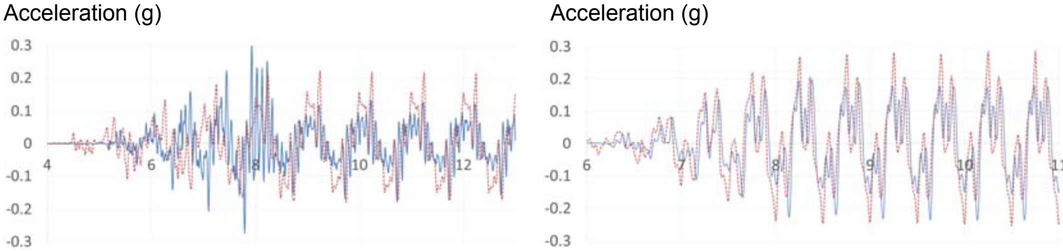


Figure 1.1 Set-up of the shake table experiments

Under harmonic shaking, with a low frequency as shown in the left Figure 1.2, the subsurface of dry sand (solid line) will experience a large peak acceleration followed by an almost constant acceleration with a lower amplitude. In the case of saturated sand (dashed line), no acceleration spike was observed. However, in comparison, the steady-state acceleration was larger than that of dry sand.

Acceleration (g) Acceleration (g)



(a) Time (s) (b) Time (s)

Figure 1.2 Influence of saturated sand and excitation frequency of: (a) 1 Hz and (b) 2 Hz, on the subsurface acceleration

In contrast, in the case of high frequency shaking in the right figure, both dry and saturated sand did not display a peak acceleration. The steady-state acceleration of saturated sand (dashed line) was larger than that of dry sand (solid line). This result does not reflect the widely-held belief that liquefied sand will always result in lower acceleration.

Figure 1.3 shows the results of centrifuge tests conducted in Tokyo. The tests were performed using a laminar box with saturated sand and two surface mounted foundations, in one case both foundations had the same pressure (Figure 1.3(b)), while in the other case one foundation sustained twice the pressure of the other (Figure 1.3(a)). Three ramped harmonic loadings with increasing amplitude, i.e. 0.2 g, 0.3 g and 0.4 g, were used, and the subsurface displacements were measured. The objective is to measure the surface and subsurface displacements of the saturated sand and ascertain the effect of the bearing pressure.

Despite the excitation being symmetrical, when the foundations apply unequal bearing pressures, the ground response becomes unsymmetrical. This is due to the subsurface

stiffness beneath the foundation being unequal as a result of the pressure at the sand surface.

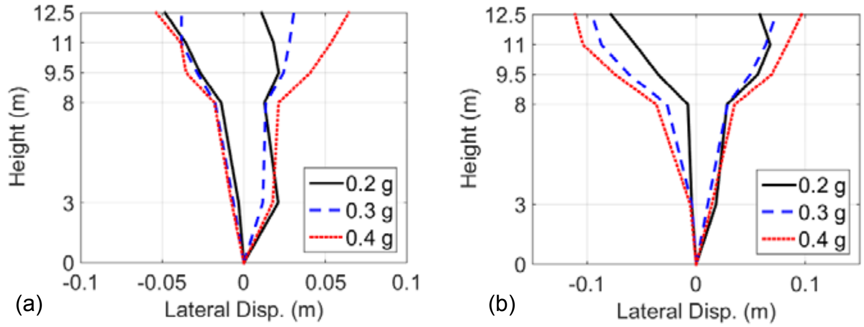


Figure 1.3 Influence of (a) unequal and (b) equal bearing pressure on subsurface displacement

The dashed line in Figure 1.4 shows the response of the stand-alone structure. The results show that, for both dry and saturated sand, the stand-alone structure experiences a larger response. The solid line represents the response of the structure enclosed in a cluster.

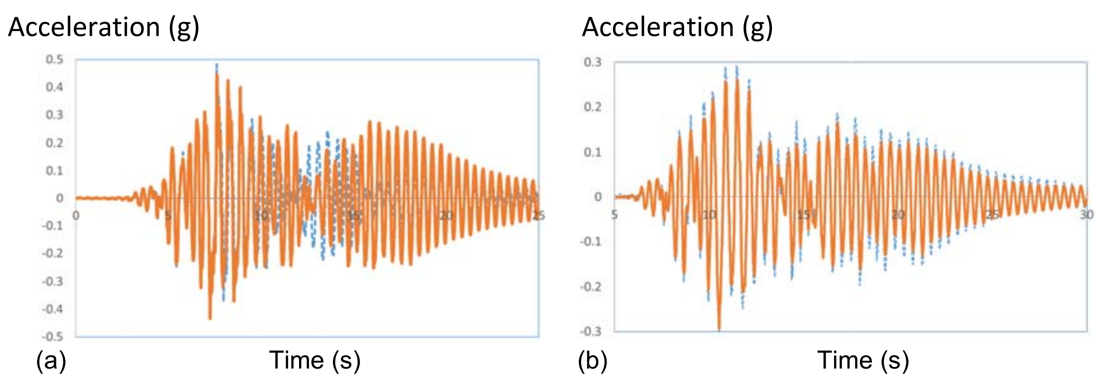


Figure 1.4 Effect of a cluster of structures on the top acceleration of a structure due to RHSC seismic motion: (a) dry and (b) saturated sand

Figure 1.5 shows the influence of neighbouring structures and saturated sand on the maximum top acceleration of the structure due to the four Canterbury earthquake records, i.e. CCCC, RKAC, CACS and RHSC observed in the large laminar box experiments.
The results show that the saturated sand does not always significantly reduce the response of the structure, independently of whether the structure stands alone or in a cluster. In general, a structure within the centre domain of the cluster experiences the smallest accelerations.

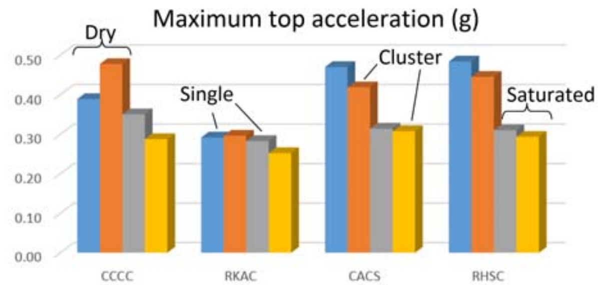


Figure 1.5 Influence of saturated sand and clustered structures on the maximum acceleration of a structure

Corresponding numerical investigations have been performed using FLIP and GEFDyn software. The results confirm the influence of the closely adjacent structures. The adjacent structures provide a large confining pressure within the body of soil, thus reducing the displacement of soil below the structures and give a higher resistance to drainage (see research outputs).

List of outputs

1. G. Barrios (2017) Seismic behaviour of clustered structures in liquefiable soil, *PhD thesis*, the University of Auckland (in preparation).
2. G. Barrios, K. Uemura, N. Kikkawa, K. Itoh, T. Larkin, R. Orense, N. Chouw (2017) Centrifuge test of adjacent shallow footings on liquefiable soil, *Journal of Earthquake Engineering* (under review)
3. R. Orense, Y. Hong, Y. Lu (2017) Numerical simulation of liquefaction effects on adjacent buildings with shallow foundations, *International Workshop on Seismic Performance of Soil-Foundation-Structure Systems*, the University of Auckland, 21-22 November 2016.
4. R. Takatoku, K. Uemura, B. Gonzalo, N. Kikkawa, N. Hiraoka, K. Itoh, N. Suemasa, N. Chouw, T. Larkin, R. Orense (2017) Influence of liquefaction on soil-foundation-structure interaction, *7th Int. Conf. on Geotechnique, Construction Materials and Envi*ronment, Mie, Japan, 21-24 Nov., ISBN: 978-4-9905958-8-3 C3051
5. R. Takatoku, K. Uemura, K. Itoh, N. Suemasa, N. Kikkawa, N. Hiraoka, G, Barios, N. Chouw, T. Larkin, R. Orense (2017) 隣接構造物における液状化挙動に関する研究 (A study of liquefaction behaviour on adjacent structures), *52nd Japan National Conference on Geotechnical Engineering,* Nagoya, Japan, 12 – 14 July (in Japanese)
6. R. Takanori, K. Uemura, K. Ito, N. Suemasa, N. Yoshikawa, N. Hiraoka, G, Barrios, N. Chouw, T. Larkin, R. Orense (2017) 上載構造物が液状化挙動におよぼす影響についての検討 (Study on the influence of overlying structure on liquefaction behaviour), *37th Conference of Kanto Branch, Japan Society of Civil Engineers*, Shinjuku, Tokyo, Japan, 12-13 March (in Japanese)
7. G. Barrios, K. Uemura, N. Kikkawa, K. Itoh, T. Larkin, R. Orense, N. Chouw (2017) Influence of bearing pressure on the liquefaction-induced settlement due to consecutive ground shakings, *International Workshop on Seismic Performance of Soil-Foundation-Structure Systems*, the University of Auckland, 21-22 November 2016.
8. R. Takatoku, K. Uemura, K. Itoh, S. Akira, N. Kikkawa, H. Nobutaka, B. Gonzalo, N. Chouw, T. Larkin, R. Orense (2016) 単一および隣接構造物における液状化挙動に関する研究 (Research on effect of liquefaction on single and adjacent structures), *Geo-Kanto Conference*, Japanese Geotechnical Society, Miraikan, Tokyo, Japan, 21 October (in Japanese)

9. G. Barrios, T. Larkin, N. Chouw (2017) Influence of liquefaction and adjacent structures on the structural response, *16th World Conference on Earthquake Engineering*, 9-13 January, Santiago, Chile
10. G. Barrios, T. Larkin, N. Chouw (2017) Numerical analyses of interaction between adjacent structures on liquefied soil, *16th World Conference on Earthquake Engineering*, 9-13 January, Santiago, Chile
11. Y. Hong, Y. Lu, R. Orense (2017) Effective stress simulation of liquefaction-induced building settlements, *16th World Conference on Earthquake Engineering*, Santiago, Chile, 9-13 January 2017, Paper No. 283, 12pp.
12. G. Barrios, N. Chouw (2015) Influence of liquefaction and SFSI on structural responses, *10th Pacific Conference on Earthquake Engineering, Building an Earthquake-Resilient Pacific*, 6-8 November 2015, Sydney, Australia.
13. R. Orense, Y. Mirjafari, S. Asadi, M. Naghibi, X. Chen, O. Altaf, B. Asadi (2017) Ground performance in Wellington waterfront area following the 2016 Kaikōura earthquake, *Bulletin of the New Zealand Society for Earthquake Engineering*, 50 (2), 142-151.

List of end-users

The end-users are listed in the section '**Dissemination of research outcomes**' and include the following: AECOM, Auckland City Council, BECA, Christchurch City Council, Department of Building and Housing, Downer EDI Works Ltd, Fletcher Building Group, New Zealand Society for Earthquake Engineering, New Zealand Transport Agency, Wellington City Council.

❖ 1.2 Research Aim

Title: Development of holistic seismic design of clustered soil-foundation-structure systems

Budget: $148,750

Research Aim achieved? Yes

This research aim will develop an understanding of the dynamics of the soil-foundation-structure system that will lead to economic resilient aseismic design and provide the basis for holistic design of groups of closely clustered buildings. This will enable rehabilitation and retrofitting of existing buildings as well as design of new facilities.

Discussion

The dynamic properties of the structure without and with the supporting soil are not the same. For example, in the case of a structure with a fixed base the natural frequency is 2.1 Hz (see Figure 2.1). However, the properties of the soil-foundation-structure system will be affected not only by the supporting soil, but also by the presence of closely adjacent structures. In addition, the free vibration resulting from a direct excitation of a structure will depend upon the distribution of stiffness, mass along the structure and the boundary conditions. In contrast, the free vibration of the structure, induced by wave propagation through the sand from the shake table to the foundation of the structure, will be affected not only by the structure but also by the supporting sand and the contact interface between the foundation and the sand, i.e. the different set of boundary conditions for the structure. The results also show that the location of a particular structure within a cluster of structures is important (see Figure 2.1). The solid and dashed lines are the response of the same structure; however, in one case (dashed line) it is stand alone, and the natural frequency obtained is 2.15 Hz, while in the other case it is positioned within a cluster (solid line) and the natural frequency is 2.22 Hz. Both frequencies are different from that of a fixed-base structure.

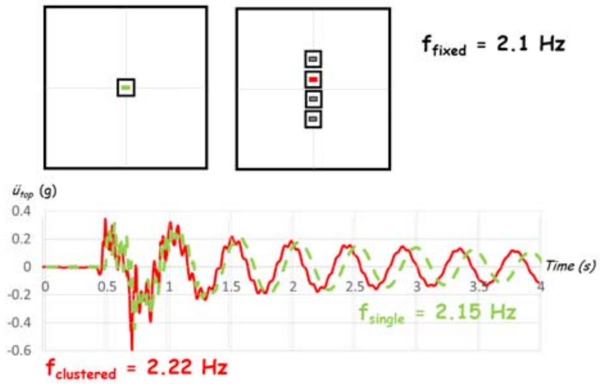


Figure 2.1 Influence of supporting soil and adjacent structures on the natural frequency of the structure-foundation-soil system

The seismic response, including the structural acceleration which leads directly to forces applied to the structure, depends not only on the dynamic properties of the structure and the characteristic of the seismic waves, but also on the properties of the supporting soil and those of the closely adjacent structures. A very important outcome of this research is the experimental evidence that the response may be significantly affected by the location of the structure, relative to the neighbouring structures.

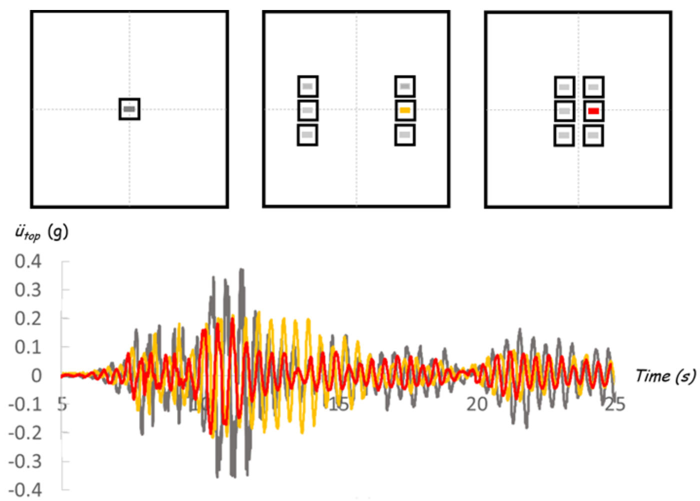


Figure 2.2 Influence of the location of the structure on the top acceleration due to the Canterbury ground motion at Canterbury Aero Club station (CACS)

In the example above a cluster of six structures causes a reduction of the structural response (marked in red in the right configuration, Figure 2.2) due to the ground motion recorded at the Canterbury Aero Club (CACS) station. An adjacent structure on both sides of the observed structure (marked by yellow, the middle configuration) also reduces the structural response, in comparison with the response of a single structure (left configuration).

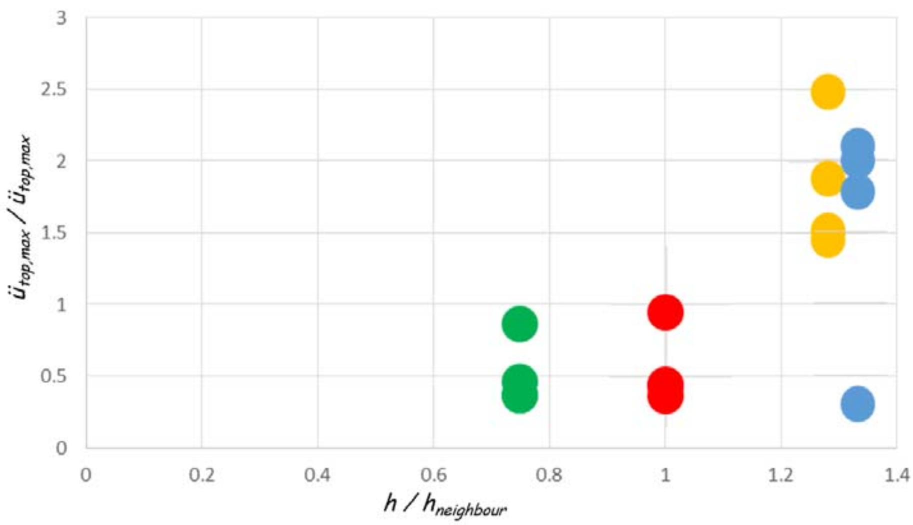


Figure 2.3 The effect of an adjacent structure on the top maximum acceleration

Figure 2.3 shows the influence of the aspect ratio, $h/h_{\text{neighbour}}$, of two structures on the ratio of the maximum top acceleration of a single structure without and with an adjacent structure. Both structures are founded on supporting soil and subjected to the Canterbury earthquake as recorded at stations CCCC, RKAC, CACS and RHSC. With an aspect ratio equal to and less than one, the adjacent structure causes a reduction in the maximum response. In contrast, an aspect ratio larger than one can cause a significant amplification.

In summary, the current common practice of assuming fixed-base structures leads to an incorrect evaluation of seismic response.

Dissemination of research outcomes

1) To achieve active interaction with other researchers working in a similar field, Nawawi has initiated and chaired the mini-symposium "Influence of liquefiable soil on single and closely clustered structures" at the VII European Congress on Computational Methods in Applied Sciences and Engineering, 5-10 June 2016 in Crete Island, Greece.
2) The international workshop on seismic performance of soil-foundation-structure systems was held on 21 and 22 November 2016 at the University of Auckland. All speakers were by invitation only. To enable fruitful exchange and develop understanding, in order to encourage holistic consideration of the whole soil-foundation-structure systems, world leading experts in the fields of structural and soil dynamics were intentionally invited. The workshop was attended by an additional 15 colleagues from industry.
   The programme of the workshop is attached and the proceedings published by CRC Press, have been submitted to the NHRP.
3) To enable practicing engineers to have insight into the most recent developments in numerical analysis, a seminar was held at the University of Auckland on 'Recent advances in analysis of liquefaction', 23 November 2016.
4) At the last World Conference on Earthquake Engineering in Santiago, Chile, 9-13 January 2017, we initiated a special session to receive feedback from international audience.
   The special session addressed the topic of 'The impact of liquefiable soil on single and closely clustered structures', which we convened. Three whole day sessions were dedicated to this topic with 24 papers. We contributed four papers (see research outputs).
5) A whole day seminar on "Seismic performance of structure-foundation-soil systems" was presented, with discussion sessions, in Wellington, Nelson, Christchurch and Auckland.

The objective was to transfer understanding, from the insights obtained from the research work, to practicing engineers.

Eighty eight participants attended the seminars, representing

Christchurch City Council,
Forbes Consultants,
Ashby Consulting Ltd,
CLC Consulting Group,
KGA Geotechnical Group Ltd,
Tonkin + Taylor,
Soil + Rock Consultants,
Markplan Consulting Ltd,
MTL Civil LTD,
Structural Sense,
Structus,
Engineering Design Consultants Ltd,
Haigh Workman,
GDC Consultants,
Riley Consultants,
Hiway Geotechnical,
Beca, BCD Group Ltd,
Kevin O'Connor & Associates Ltd,
E. Holt Ltd,
Compusoft Engineering Ltd,
Mainmark Ground Engineering,
Holmes Consulting Group,
Aurecon NZ Ltd,
Batchelar McDougall Consulting Eng.,
Miyamoto International,
Opus International Consultants,
Geotech Consulting Ltd,
Stantec,
NZET Consulting Engineers Ltd,
Calibre Consulting Ltd,
Jacobs Engineering Ltd,
Resource Development Consultants Ltd,
TSE Taranaki & Associates Ltd,
Coffey Services NZ Ltd,
Sawrey Consulting Engineers,
ETS Engineers Ltd,
Davidson Group,
CGW Consulting Engineers.

The programme of the seminars, from 21 to 24 August 2017, is attached.

List of outputs

1. X. Qin, N. Chouw (under review) Shake table test of structure-soil-adjacent structure interaction, *Earthquakes and Structures*
2. X. Qin, N. Chouw (in print) Shake table study on the effect of mainshock-aftershock sequences on structures with SFSI, *Shock and Vibration*
3. Y. Lim (2017) Interaction between clustered structures under impact and pulse loading, *ME project*, the University of Auckland
4. N. Chouw (2017) Low-damage design philosophy for future earthquake-resistant structures, *ASME PVP Conference*, 16-20 July, Waikoloa, Hawaii, USA
5. X. Qin, N. Chouw (2017) Experimental study of clustered structures with SFSI, *16th World Conference on Earthquake Engineering*, 9-13 January, Santiago, Chile
6. N. Chouw, T. Larkin (2016) The effect of the underlying soil on earthquake response of buildings and bridges, *NatHaz 2015*, http://www.naturalhazards.org.nz/NHRP/Publications /Natural-Hazards-Issues
7. T. Larkin, X. Qin, N. Chouw (2016) Effect of local site on SFSI of clustered structures, *NatHaz16 – Soil characterization and site effects*, 23 April, Sao Miguel, Portugal
8. X. Qin, N. Chouw, T. Larkin (2016) Effect of higher modes on the response of structures with nonlinear soil-foundation-structure interaction, *VII European Congress on Computational Methods in Applied Sciences and Engineering*, Crete Island, Greece, 5-10 June 2016
9. G. Barrios, T. Larkin, N. Chouw (2016) Influence of structural slenderness on the seismic response of clustered structures, *VII European Congress on Computational Methods in Applied Sciences and Engineering*, Crete Island, Greece, 5-10 June 2016
10. X. Qin, T. Larkin, N. Chouw (2016) Holistic seismic design of clustered soil-foundation-structure systems using a large laminar box, *NZ Geomechanics News*
11. T. Zhang, N. Chouw, M. Moghaddasi (2015) A parametric study of nonlinear soil-structure interaction effects on structural response in far-field earthquakes, *10th Pacific Conference on Earthquake Engineering, Building an Earthquake-Resilient Pacific*, 6-8 November 2015, Sydney, Australia.

List of end-users

The list of end-users include the following: AECOM, Auckland City Council, BECA, Christchurch City Council, Department of Building and Housing, Downer EDI Works Ltd, Fletcher Building Group, New Zealand Society for Earthquake Engineering, New Zealand Transport Agency, Wellington City Council.

Conclusions & Recommendations:

In conventional engineering practice worldwide civil engineers employ fixed-base analyses in their seismic design. Thus, the diverse nature of the supporting soil, including liquefied soil, is completely missing. Furthermore, current design practices also ignore the influence of neighbouring structures.

This research shows that inclusion of the supporting soil significantly affects the seismic response of a stand-alone structure, both in frequency content and magnitude, especially in situation of liquefaction. This has a direct bearing on the seismically induced forces on the structural components. Hence, the seismic resilience needs readdressing to incorporate recent knowledge.

The results of the large laminar box and centrifuge experiments of a cluster of structures indicate that with regard to seismically induced forces:

1. No structure can be considered stand alone.
2. The response of a particular structure depends upon its relative location in the cluster.
3. Clustering of structures leads to a change in the wave field beneath the structures.
4. The aspect ratio of the neighbouring structures affect the response of all the structures.
5. The configuration of a cluster of structures is one of the variables defining the response of the group.
6. The presence of a cluster of structures increases the confining stress in the supporting soil. This lead to an increase in wave velocities.
7. An increase in confining stress in soil beneath a cluster of structures affects the development of excess pore water pressure and the overall structural response.

The outcomes of this research show that the following investigations will bear fruit for design engineers:

1. The influence of the local site on the actual ground excitation of the structure
2. The consequence of liquefaction and multi-axial ground excitations on
   a) a single structure
   b) closely adjacent structures
   c) a cluster of structures
3. Recent investigations in seismic-tectonic of New Zealand continually lead to the discovery of new faults. Considering the extent of New Zealand relative to the primary axis of the faulting system, most of our town and cities are within the range that necessitates them to be considered as a near source, or nearly so. Thus, the effect of near-source excitation on a stand-alone structure and a cluster of structures needs urgent consideration.

Acknowledgements:

1. We are very appreciative of the financial support by the Ministry of Business, Innovation and Employment through the Natural Hazards Research Platform.

We also would like to thank the following people and organizations for their generous help and support that enabled us to exceed the expectations of the research project.

2. Professor K. Itoh of Tokyo City University and Dr N. Kikkawa of the National Institute for Occupational Safety and Health in collaboration with colleagues in Tokyo for enabling us to perform the centrifuge experiments on the impact of liquefied sand on shallow foundations.
3. Professor Susumu Iai of Kyoto University, Japan, for contributing to the seminars in four cities on seismic performance on structure-foundation-soil systems.
4. Professors I. Towhata (University of Tokyo, Japan), H. Hao (Curtin University, Australia), K. Stokoe (University of Texas, USA), I. Dimitrakopoulos (Hong Kong University of Science and Technology, China), H. Osinga (University of Auckland), S. Iai (Kyoto University, Japan), H. Werkle (University of Applied Sciences Konstanz, Germany), I. Takewaki (Kyoto University, Japan, and A.H.C. Chan (University of Tasmania, Australia), Drs Y. Tamari (Tokyo Electric Power, Japan), J. Toh (PSM, Australia), Dr M. Millen (University of Canterbury), Dr L. Storie (Tonkin and Taylor) and A.K. Murashev (OPUS) for contributing to the international workshop on seismic performance of soil-foundation-structure systems.

References:

[1] H. Aldaikh, N.A. Alexander, E Ibraim, J. Knappett (2016) Shake table testing of the dynamic interaction between two and three adjacent buildings (SSSI), Soil Dynamics and Earthquake Engineering 89:219-232

[2] Q. Ge, F. Xiong, J. Zhang, J. Chen (2016) Shaking table test of dynamic interaction of soil-high rise buildings, European Journal of Environmental and Civil Engineering, 1-23

[3] J. Knappett, P. Madden, K. Madden (2015) Seismic structure-soil-structure interaction between pairs of adjacent building structures, Geotechnique 65(5): 101-113

[4] N.A. Alexander, E. Ibraim, H. Aldaikh (2013) A simple discrete model for interaction of adjacent buildings during earthquakes, Computers and Structures 124: 1-40

[5] C. P. Hayden (2014) Liquefaction-induced building performance and near-fault ground motions, PhD thesis, University of California, Berkeley.

[6] N.W. Trombetta, H. Benjamin Mason, T.C. Hutchinson, J.D. Zupan, J.D. Bray, B.L. Kutter, (2014) Nonlinear soil–foundation–structure and structure–soil–structure interaction: engineering demands. Journal of Structural Engineering, 141(7), 04014177

[7] Aldaikh, H. S. (2013) Discrete models for the study of dynamic structure-soil-structure interaction. Doctoral dissertation, University of Bristol

[8] Bertalot, D. (2013) Seismic behaviour of shallow foundations on layered liquefiable soils, PhD thesis, University of Dundee

[9] Dashti, S. (2009) Toward developing an engineering procedure for evaluating building performance on softened ground. PhD thesis, University of California, Berkeley

List of Figures:

Appendices: List them here or include as attachment(s).

1. Most of the publications, when they become available or are published, can be downloaded from https://www.researchgate.net/profile/Nawawi_Chouw/contributions
2. The PhD thesis of Xiaoyang Qin on 'Experimental studies of structure-foundation-soil interaction effect on upliftable structures' can be downloaded from the following link: https://researchspace.auckland.ac.nz/handle/2292/29301
3. The PhD thesis of Gonzalo Barrios on 'Seismic behaviour of clustered structures in liquefiable soil' can be downloaded from the following link, once it is available. https://researchspace.auckland.ac.nz/handle/2292/1/discover
4. The programme of the international workshop on soil-foundation-structure systems
5. The programme of the seminar in Wellington, Nelson, Christchurch and Auckland

Attachment 1: The programme of the international workshop on soil-foundation-structure systems

International Workshop on Seismic Performance of Soil-Foundation-Structure Systems

The University of Auckland, 38 Princes Street, Building 303-G02 (Street level), Room PLT2

Workshop Programme

Day 1 (Monday, 21 November 2016)	
8:00 – 8:40	Registration
8:40 – 9:00	Opening session: Welcome remarks by the President of the New Zealand Society for Earthquake Engineering, P.C. Smith and University of Auckland representative
9:00 – 10:05	Session 1 (Chairman: N. Chouw)
	Presentation 1: I. Towhata, University of Tokyo, Japan *Findings from 2016 Kumamoto earthquake sequence in Japan*
	Presentation 2: H. Hao, K. Bi, C. Li, H. Li, Curtin University, Australia *Simulation of subsea seismic ground motions*
	Presentation 3: O. Kacar, K. Stokoe, University of Texas, USA *Shallow foundation settlements on granular soils due to the generation of pore water pressure*
10:05 – 10:30	Morning coffee/tea break
10:30 – 12:00	Session 2 (Chairman: C.Y. Chin)
	Presentation 4: Z. Shi, I. Dimitrakopoulos, Hong Kong University of Science and Technology, China *Comparative study of deck-abutment interaction with different contact models*
	Presentation 5: R. Orense, Y. Hong, Y. Lu, University of Auckland, NZ *Numerical simulation of liquefaction effects on adjacent buildings with shallow foundations*
	Presentation 6: Y. Tamari, Y. Nakagama, M. Kikuchi, M. Morohashi, T. Kurita, Y. Shingaki, Y. Hirata, R. Ohnogi, H. Nakamura, Tokyo Electric Power Services, Japan *A Study on Seismic behavior of foundations of transmission towers during the 2011 off Pacific coast of Tohoku earthquake*
	Presentation 7: E. Lim, L. Jiang, N. Chouw, University of Auckland, NZ, and Central South University, China *Seismic performance of a non-structural component with two supports in bi-directional earthquakes considering soil-structure interaction*
12:00 – 13:30	Group photo and lunch break

13:30 – 15:00	Session 3 (Chairman: R. Orense)
	Presentation 8: J. Toh, PSM, Australia *Seismic ground-structure interaction, a geotechnical practitioner's perspective*
	Presentation 9: L. Hogan, M. Pender, L. Wotherspoon, University of Auckland, NZ *Pile head lateral displacement amplitude dependent damping determined from near-prototype scale snap-back testing*
	Presentation 10: C. Kun, L. Jiang, N. Chouw, University of Auckland, NZ, and Central South University, China *Investigation of the influence of soil-structure interaction on the seismic performance of a skewed bridge*
	Presentation 11: S. Iai, K. Ueda, T. Tobita, Kyoto University, Japan *Soil-foundation-structure-fluid interaction during earthquakes*
15:00 – 15:30	Afternoon coffee/tea break
15:30 – 17:30	**Discussion Session 1** (Leaders: S. Iai and H. Hao) Topic: *Dynamics of soil-foundation-structure systems*
18:30 –	Workshop Dinner (Top of the Town, Pullman Hotel, Auckland)
Day 2 (Tuesday, 22 November 2016)	
9:00 – 10:30	Session 4 (Chairman: M. Pender)
	Presentation 12: H. M. Osinga, University of Auckland, NZ *A mathematical approach to computing structural-failure boundaries*
	Presentation 13: M. Millen, M. Cubrinovski, S. Pampanin, University of Canterbury, NZ *Conceptual framework for incorporation of SFSI effects in structural assessment*
	Presentation 14: H. Werkle, University of Applied Sciences Konstanz, Germany *Modeling of soil-foundation-structure interaction for earthquake analysis of 3D BIM models*
	Presentation 15: L.B. Storie, M.J. Pender, J.A. Knappett, Tonkin & Taylor Ltd, NZ *Centrifuge modelling of the seismic response of multi-storey buildings on raft foundations to the Christchurch Earthquake*
10:30 – 11:00	Morning coffee/tea break
11:00 – 12:30	Session 5 (Chairman: T. Larkin, TBC)
	Presentation 16: S. Van Ballegooy, Tonkin & Taylor Ltd, NZ *Prediction of liquefaction-induced foundation damage of light weight, timber framed, single storey residential buildings*
	Presentation 17: I. Takewaki, K. Kojima, Kyoto University, Japan *Double, triple and multiple impulses for critical elastic-plastic earthquake response analysis to near-fault and long-duration ground motions*

	Presentation 18: A. K. Murashev, C. Keepa, A. Tai, OPUS, NZ *Performance based design of a structural foundation on liquefiable ground with a natural soil crust*
	Presentation 19: G. Barrios, K. Uemura, N. Kikkawa, K. Itoh, T. Larkin, R. Orense, N. Chouw, University of Auckland, and National Institute of Occupational Safety and Health, Japan *Influence of foundation bearing pressure on liquefaction-induced settlement due to consecutive ground shakings*
12:30 – 13:30	Lunch break
13:30 – 15:00	Session 6 (Chairman: A.H.C. Chan)
	Presentation 20: X. Qin, L. Jiang, N. Chouw, University of Auckland, and Central South University, China *A large scale shake table test on the seismic response of a structure with SFSI and uplift*
	Presentation 21: A. H. C. Chan, X. Zhang, L. Tang, X. Z. Ling, University of Tasmania, Australia, and Harbin Institute of Technology, China *Effect of ground motion characteristics on seismic response of pile foundations in liquefying soil*
	Presentation 22: C. Barrueto, E. Saez, C. Ledezma, Pontifica Universidad Catolica de Chile, Chile *Seismic demand on piles in sites prone to liquefaction-induced lateral spreading*
15:00 – 15:30	Afternoon coffee/tea break
15:30 – 17:30	**Discussion Session 2** (Leaders: M. Pender and I. Takewaki) Topic: *Nonlinear soil-foundation-structure interaction*
17:30 – 17:45	Closing Session
17:45 – 18:15	Socials

To ensure fruitful discussions the number of participants will be limited. The registration form can be downloaded from the workshop webpage below (first come first served)
http://www.engineering.auckland.ac.nz/en/about/events/events-2016/uaceer-seismicperformance.html

Participants of the 2016 International Workshop on Seismic Performance of Soil-Foundation-Structure Systems

Participants of the 2016 International Workshop on Seismic Performance of Soil-Foundation-Structure Systems

Attachment 2: The programme of the seminar in Wellington, Nelson, Christchurch and Auckland

The seminar will assist in the understanding of:

- the importance of the incorporation of the foundation soil in determining seismic response
- the effect of closely adjacent structures on individual and grouped structures
- the elements of a probabilistic seismic hazard analysis and NZS 1170.5
- some of the difficulties with site classification according to NZS 1170.5
- the response of saturated sand to earthquake loading
- the role of adjacent buildings on liquefaction-induced settlement and pore water pressure response
- the role of structures in modifying free-field saturated sand response
- the consequence of near-source earthquakes for the development of excess pore water pressure
- a recent Japanese approach to retaining wall design based on effective stress analysis of soil-structure systems.
- a holistic consideration of the main structure, secondary and non-structural components and foundation and supporting soil to determine seismic loading
- the effect of concurrent vertical and horizontal motion and near source effects on the loads of non-structural elements

Other benefits

- Interaction with knowledgeable speakers
- The opportunity to network with industry and academic peers

Who should attend

The seminar will be of interest to structural and geotechnical engineers and designers, specialists in seismic assessment of structures and earthquake risk in general, and to researchers interested in exploring various facets of soil-structure interaction during earthquakes. This seminar aims to provide up-to-date information on recent developments in the seismic performance of structure-foundation-soil systems. It will address a wide range of practical issues including probabilistic seismic hazard analysis and NZS 1170.5, the incorporation of the foundation soil in determining seismic response, effects of closely adjacent structures on individual and grouped structures in both dry and liquefiable ground, recent Japanese approach to retaining wall design and secondary and non-structural components.

Programme

8:30- 9:00	Registration	12:45-14:00	3rd speaker
9:10- 10:25	1st speaker	14:00-14:20	Coffee/tea break
10:25-10:45	Coffee/tea break	14:20-15:35	4th speaker
10:45-12:00	2nd speaker	15:35-15:50	Discussion session
12:00-12:45	Lunch	15:50-16:00	Closing remark

Speakers' topics and profiles

Fundamental difficulty in using response spectrum method and recent knowledge on clustered structure response

Nawawi Chouw (Dr.-Ing., Associate Professor)

Summary

A description of common misunderstanding of the use of the response spectrum approach will be given including in understanding the role of the peak ground acceleration. Examples of earthquake-induced structural response, in the relationship to the response spectrum, will be given using real earthquake records. The importance of the incorporation of the foundation soil in determining the structural response will be discussed. In conventional seismic design the structure is often considered isolated from its surroundings. In reality, in particular in CBDs, structures are located closely adjacent to each other. Recent works have brought out the effects of these close coupling on seismic responses. In this seminar these recent research finding will presented and discussed.

Bio

Nawawi has extensive teaching and research experience in earthquake engineering. He led the University of Auckland Centre for Earthquake Engineering Research from 2011 to 2017. Prior to joining the University of Auckland he worked at universities in Germany, Japan and Australia. He was also invited to teach at several universities in Europe, China and Japan. He gained his doctorate in structure and soil dynamics from the Ruhr University Bochum in Germany. He has been awarded twice the Gledden Fellowship of the University of Western Australia, Fritz-Peter-Mueller Prize of the Technical University of Karlsruhe, Germany, the Best Research Award of Chugoku Denryoku Research Foundation, Japan, and received twice recognition for excellence in research supervision from Chinese Scholarship Council. He was invited by China Ministry of Education, NZ Ministry of Business, Innovation and Employment, Qatar Science Foundation, SA National Research Foundation, German Academic Exchange Service and by other European Research Institutions to assess applications. He was Guest Editor of a number of journals, e.g. Protective Structures, Soil Dynamics and Earthquake Engineering. He is an associate editor of Frontiers in Build Environment – Earthquake Engineering and is an editorial board member of a number of international journals. He teaches the courses 'Structural Dynamics', 'Advanced Structural Dynamics' and 'Dynamics of Structures in Earthquakes'.

NZS 1170.5, site classification and seismic ground response

Tam Larkin (PhD, Senior Lecturer)

Summary

The loadings standard NZS 1170.5 sets out methods of determining the classification of a site and the resulting spectral shape factors that lead to the structural actions needed in design. This presentation will contain an overview of the background to the standard and will explain in simple terms the elements that are used in a probabilistic seismic hazard analysis that is the basis for NZS 1170.5. A description of what the code is trying to achieve followed by a presentation of the uncertainties and difficulties with the definition of the C/D site classification boundary will be given.

Bio

Dr Tam Larkin is an academic member of the Department of Civil and Environmental Engineering at the University of Auckland. He has decades of teaching and research experiences in earthquake engineering including supervision of a large number of postgraduate students, especially in soil dynamics and seismology. He was recently awarded the Otto Glogau Prize of the New Zealand Society of Earthquake Engineering and the Geomechanics Prize of the New Zealand Geotechnical Society for the second time, respectively. He has recently become involved in research projects with a focus on the seismic performance of clustered structures and liquid storage tanks. He teaches the course 'Earthquake Engineering'.

Liquefaction-induced building movements

Rolando Orense (Dr. Eng, PE, MIPENZ, Associate Professor)

Summary

Earthquake-induced liquefaction has caused significant damage (e.g. settlement and tilt) to residential houses and commercial buildings on shallow foundations. In this seminar, the seismic performance of

buildings built on shallow foundations in liquefiable ground will be explained through a review of actual case histories as well as results of physical model tests and numerical analysis. The contributions of the shear-induced, volumetric-induced, and ejecta-induced ground deformation mechanisms in liquefaction-induced movements of isolated buildings will be examined, taking into account the effects of building geometry, properties and conditions of the foundation ground and characteristics of the earthquake motion. Moreover, the role of adjacent buildings on the settlement and pore water pressure development underneath the structure will also be discussed.

Bio

Rolando has extensive experience in research, teaching and consulting work on topics related to soil liquefaction, ground response analyses and soil-structure interaction during earthquakes through laboratory testing, physical modelling and numerical simulation. Prior to joining the University of Auckland, he worked at universities and consulting companies in the Philippines and in Japan. He has authored and edited three books and over 230 peer-reviewed papers in scholarly journals and international conference proceedings and over 60 technical reports. He received Best Research Paper Award, Business Plan Award and Technical Award from the Japanese Geotechnical Society. He has been involved in many post-earthquake reconnaissance investigations, all of which involved liquefaction-induced damage. Rolando currently teaches a post-graduate course in 'Geotechnical Earthquake Engineering'.

Simplified and detailed analyses of seismic performance of retaining walls during earthquakes

(Monday, 21 August – Wednesday, 23 August)
Susumu Iai (PhD, Professor)

Summary

Conventional approach for evaluating seismic performance of retaining walls during earthquakes was based on limit equilibrium with seismic earth pressures using Mononobe-Okabe equation or Newmark type sliding block analysis to evaluate the degree of deformation. A more detailed approach has been developed, which is now routinely used in practice in Japan for evaluating the seismic performance of retaining walls, especially those founded on loose liquefiable sand, when subjected to strong earthquake motion. This more recent approach is based on effective stress analysis of soil-structure systems. Advantages and disadvantages of these approaches will be discussed.

Bio

Susumu was a professor of Geo-hazards Division, Disaster Prevention Research Institute, Kyoto University, Japan. He is currently the president of the FLIP consortium specialising in the consequence of liquefied soil on structures. He graduated from the University of Tokyo in 1974 and immediately joined the Port and Harbour Research Institute. His major research interests are geotechnical earthquake engineering in waterfront areas, including soil-structure-fluid interaction analysis. He has been chairman of PIANC/MarCom/WG34: Working Group on Effects of Earthquakes on Port Structures, International Navigation Association (PIANC), 1997-2002, and convener of ISO/TC98/SC3/WG10: Seismic actions on geotechnical works, ISO, 2002-present. He was the recipient of the 1994 Outstanding Research Award from the Japanese Geotechnical Society, 1994 Prakash Award for significant contribution to geotechnical earthquake engineering; 1996 Outstanding Research Award from the Science and Technology Agency, Japanese Government and 1999 Outstanding Paper Award from the Japanese Geotechnical Society.

Current design specifications and recommendations for seismic design of non-structural components

(only on Thursday, 24 August 2017)
Ellys Lim (PhD candidate)

Summary

Secondary structures and non-structural components (SS/NSC) has always been considered less important in the seismic analysis and design in comparison to the main structure. Even though building specifications for SS/NSC exist, compliance has not been enforced. NSC in older buildings are usually deemed not requiring engineering design. In recent decades, design specifications for SS/NSC around the world have seen significant improvement. The latest New Zealand guidelines for seismic assessment in 2016 includes specific recommendations for a wide range of typical NSCs. Indirect failures of NSC is now considered a critical concern; even if the failure does not cause direct casualties,

it can pose a hazard to an adjacent structure or other SS/NSC. In practice, the challenge for proper design of NSC is often the limited time and resources. For designers and researchers, realistic prediction of the loading is relevant. For this purpose, a holistic consideration of the whole system of the main structure, SS/NSC, and foundation and supporting soil is crucial. In addition, multi-axial excitations, including vertical motion, need to be considered, especially in near-source situations. These factors, not yet considered in current design specifications, will be addressed in the seminar. The outcome of large-scale shake table experiments on the seismic performance of NSC under multi-axial excitations, including soil effect, will be presented. Available design specifications will be discussed. Recommendations for further improvement of current design specification for non-structural components will also be addressed.

Bio:
Ellys Lim is a PhD student at the University of Auckland. She has recently submitted her PhD on the seismic design of non-structural components incorporating the simultaneous influence of the interaction between main structure and non-structural components, multi-axial near-source ground motions, and soil effects. She also focuses on recommendations for further improvement of current design specifications for non-structural components. The PhD thesis contains information on a large number of large-scale shake table tests in Auckland as well as abroad. Ellys has presented her research outcomes at national and international conferences, including the 16th World Conference on Earthquake Engineering in Chile and the 2016 International Workshop on Seismic Performance of Soil-Foundation-Structure Systems in Auckland. She has submitted and published several journal and conference papers and contributed to teaching in the course of Dynamics of Structures.

Wellington:

Nelson:

Christchurch:

Auckland: