QuakeCoRE FP1 monthly meeting on 26 November 2020

QuakeCoRE
NZ Centre for Earthquake Resilience
Te Hiranga Rū

On the influence of ground densification on seismic site effects and nonlinear SSI problems

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THE UNIVERSITY OF
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NEW ZEALAND

Overview of presentation

Part 1: Influence of ground densification on seismic site effects

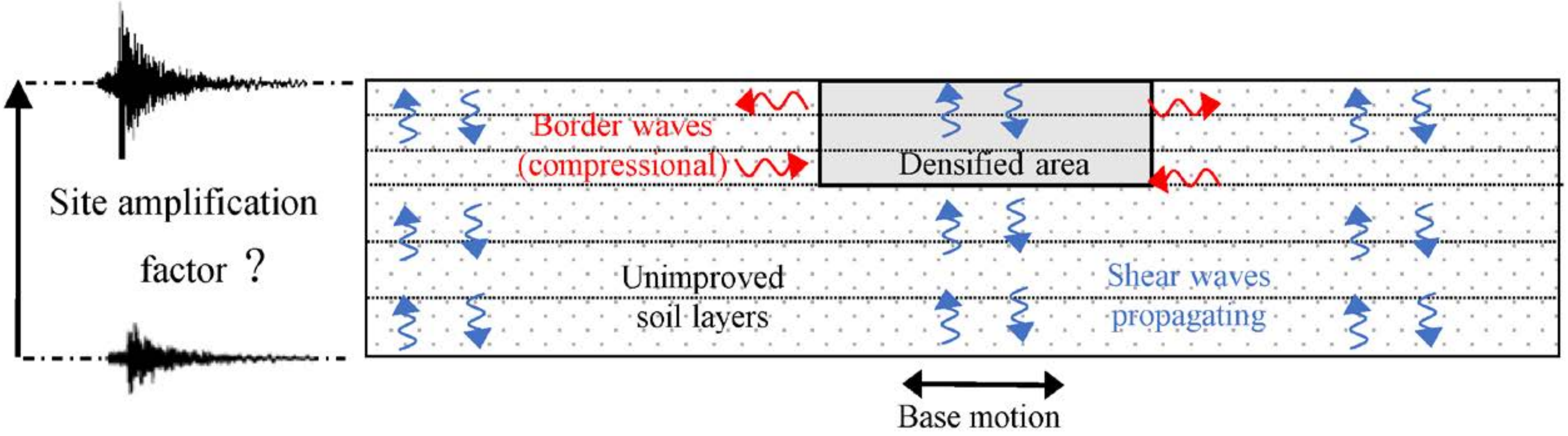
Parametric ground response analyses (GRA) were conducted over:

- ✓ 5 soil profiles;
- ✓ 36 improved soil conditions
- ✓ 18 ground motions

Part 2: A practical discussion on hazard-consistent nonlinear SSI problem

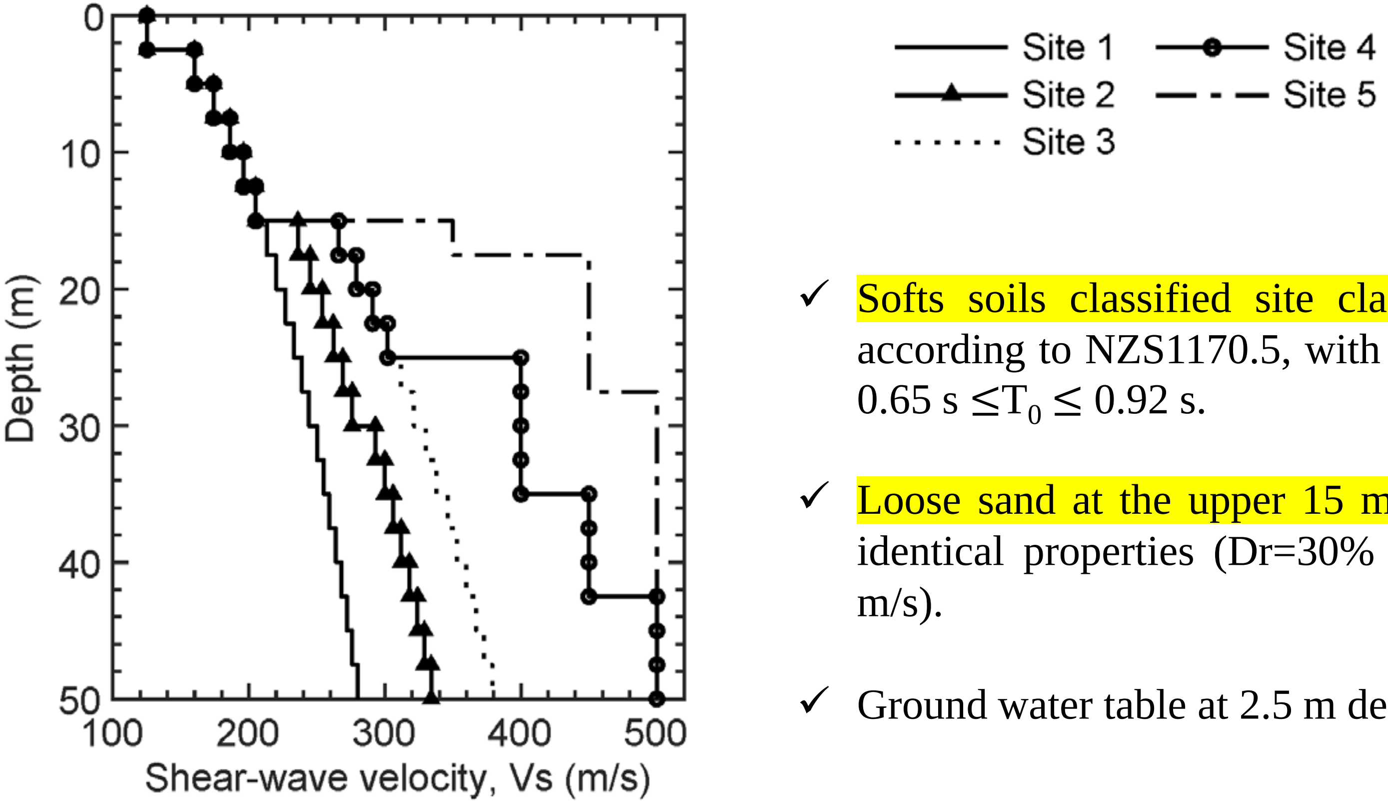
- ✓ Common practice
- ✓ Limitations
- ✓ Proposed approach

Part 1 – Principle of ground response analysis



Overview of shear plane (2-D) ground response analysis implemented to investigate the seismic site effects of ground densification.

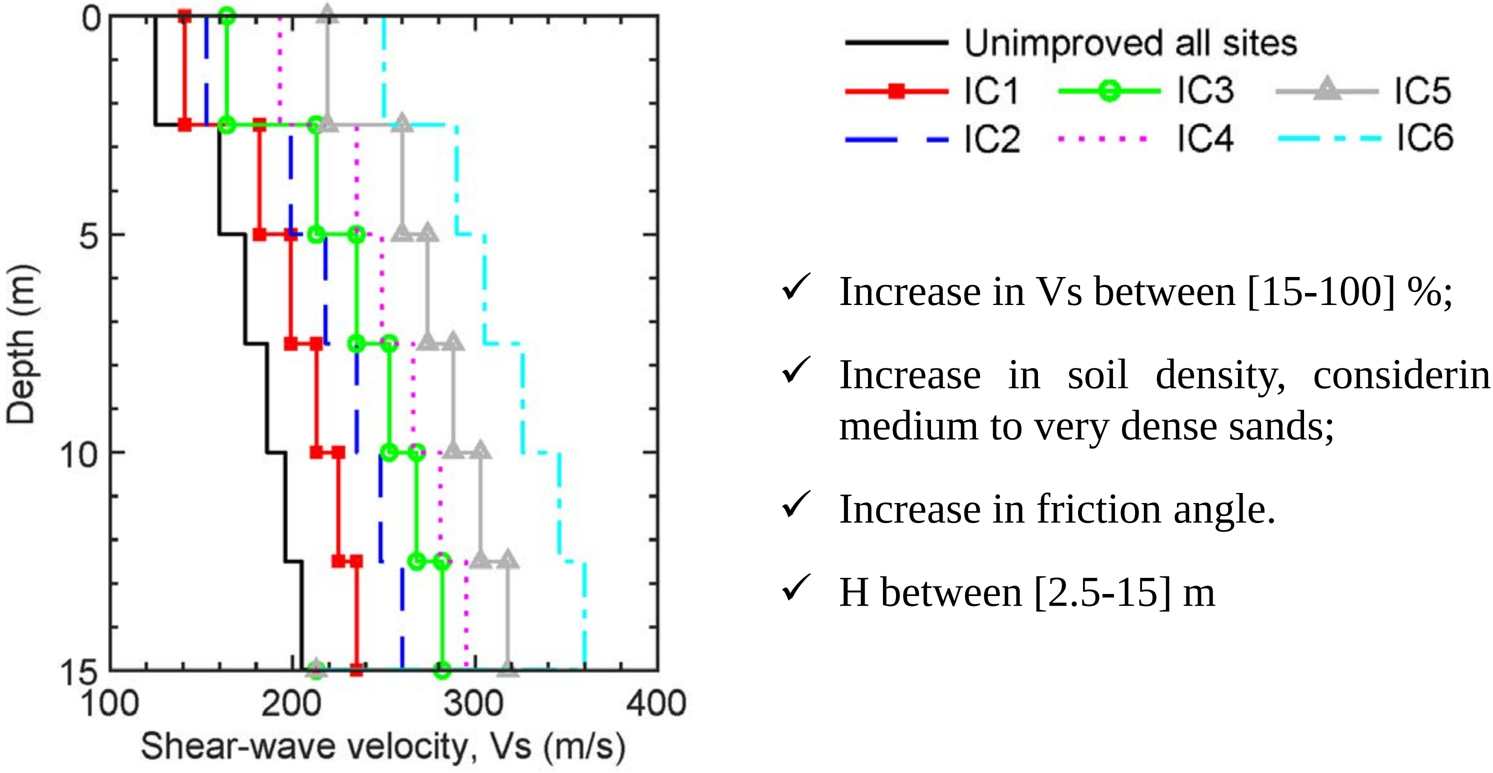
Part 1- Natural soil profiles (x5) – 50 m depth



- ✓ Softs soils classified site class D and E according to NZS1170.5, with a site period 0.65 s $\leq T_0 \leq$ 0.92 s.
- ✓ Loose sand at the upper 15 m depth, with identical properties (Dr=30% - $V_{S,15}$ =170 m/s).
- ✓ Ground water table at 2.5 m depth

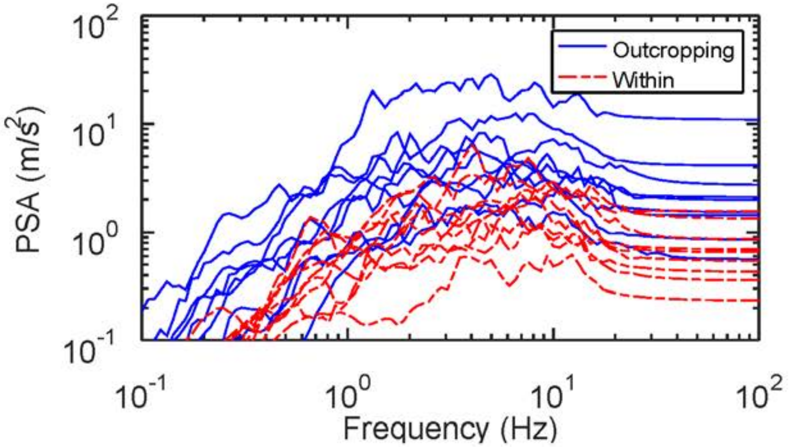
Part 1- Cases of ground densification (x36)

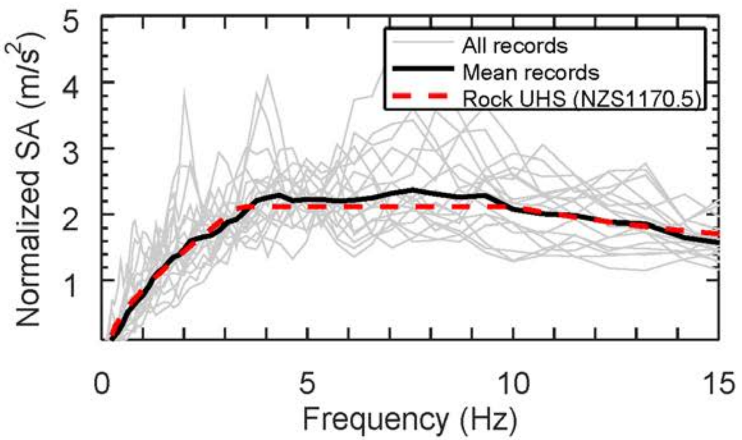
- ✓ 6 degrees of improvement (IC1 to IC6) and 6 thicknesses (H) of improvement



- ✓ Increase in Vs between [15-100] %;
- ✓ Increase in soil density, considering medium to very dense sands;
- ✓ Increase in friction angle.
- ✓ H between [2.5-15] m

Part 1 - Selected control motions (x18)





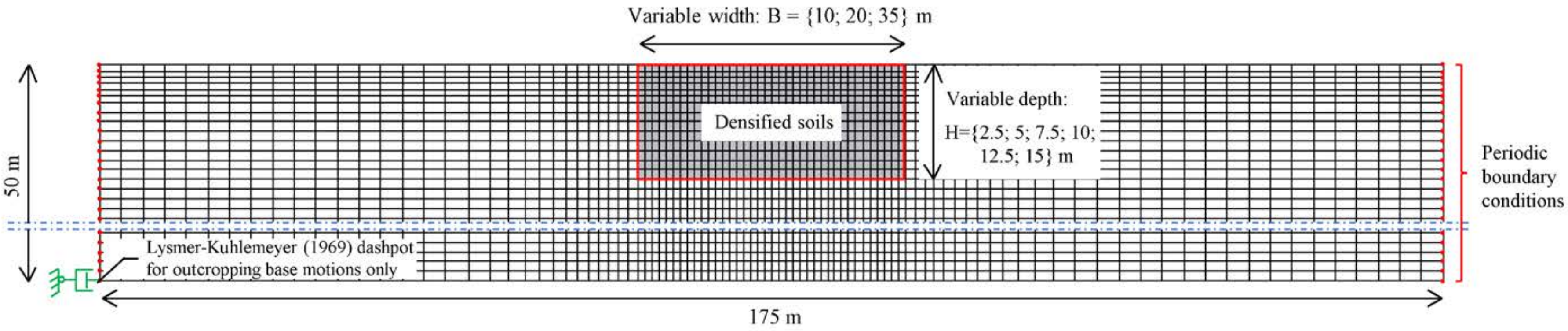
(*) Normalized PSA with PGA scaled at 1 m /s^2

18 ground motions selected from worldwide database including:

- ✓ 5 records from GEONET in outcropping rock condition
- ✓ 4 records from NGA in outcropping rock condition
- ✓ 9 records from KiK-Net in within rock condition

Part 1 - 2-D finite element model

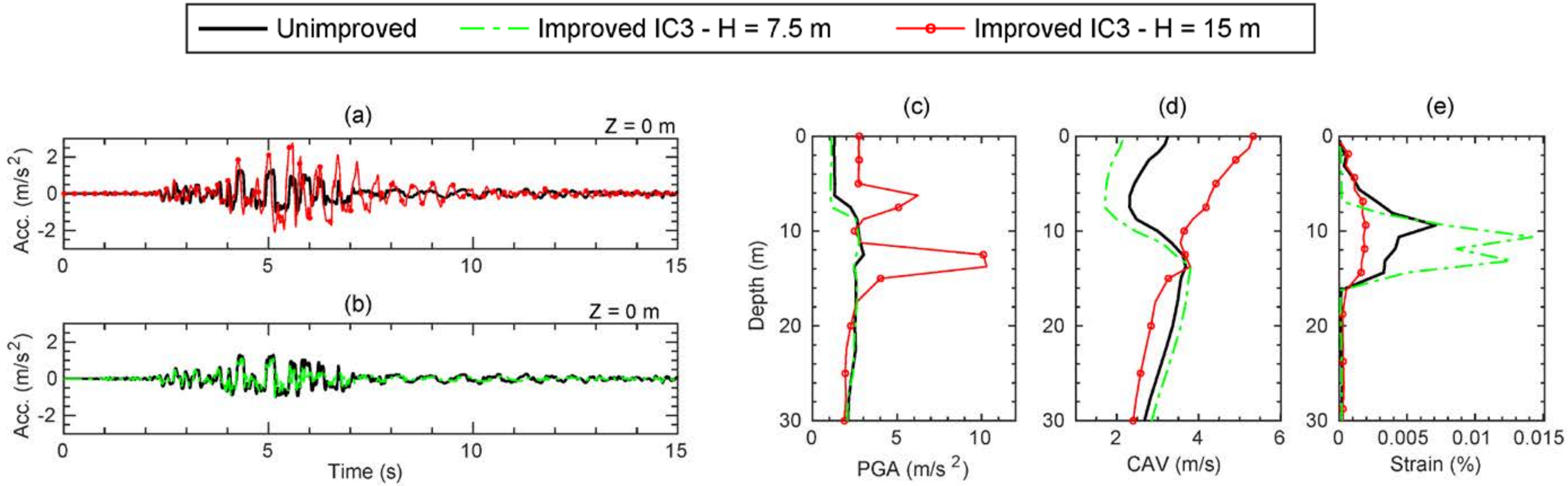
- Layout of finite element model using OpenSees:



- ✓ Fluid-solid coupled plane strain element – Quad4UP;
- ✓ Constitutive soil model PDMY02, calibrated for liquefaction after Gingery [1];
- ✓ 4116 quadrilateral elements.

[1] Gingery, J. R., 2014. Effects of Liquefaction on Earthquake Ground Motions, Ph.D. Dissertation, University of California at San Diego, San Diego, CA.

Part 1- Influence of ground densification on ground motion intensities

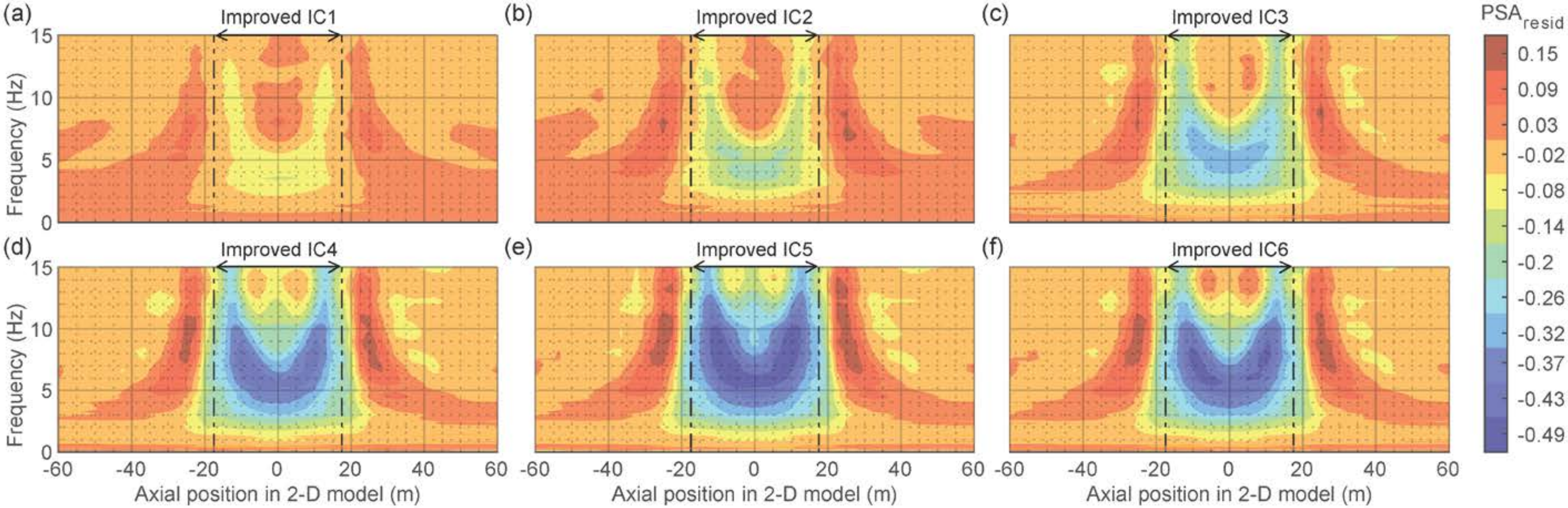


Comparison of ground motion intensities obtained by 1-D site response analysis at Site 5, using the improved condition IC3 and different thicknesses of ground densification with H = {7.5, 15} m. (a)-(b) Time-history accelerations calculated at the ground surface; (c) peak ground acceleration (PGA) in the upper 30 m; (d) cumulative absolute velocity (CAV); and (e) shear strain profile.

Part 1- Influence of ground densification when increasing the upper Vs profiles

$$\mathrm{PSA_{resid}}(f) = \ln[\mathrm{PSA_{imp}}(f)] - \ln[\mathrm{PSA_{unimp}}(f)]$$

$\mathrm{PSA_{resid}} > 0$: Amplification
$\mathrm{PSA_{resid}} < 0$: De-amplification



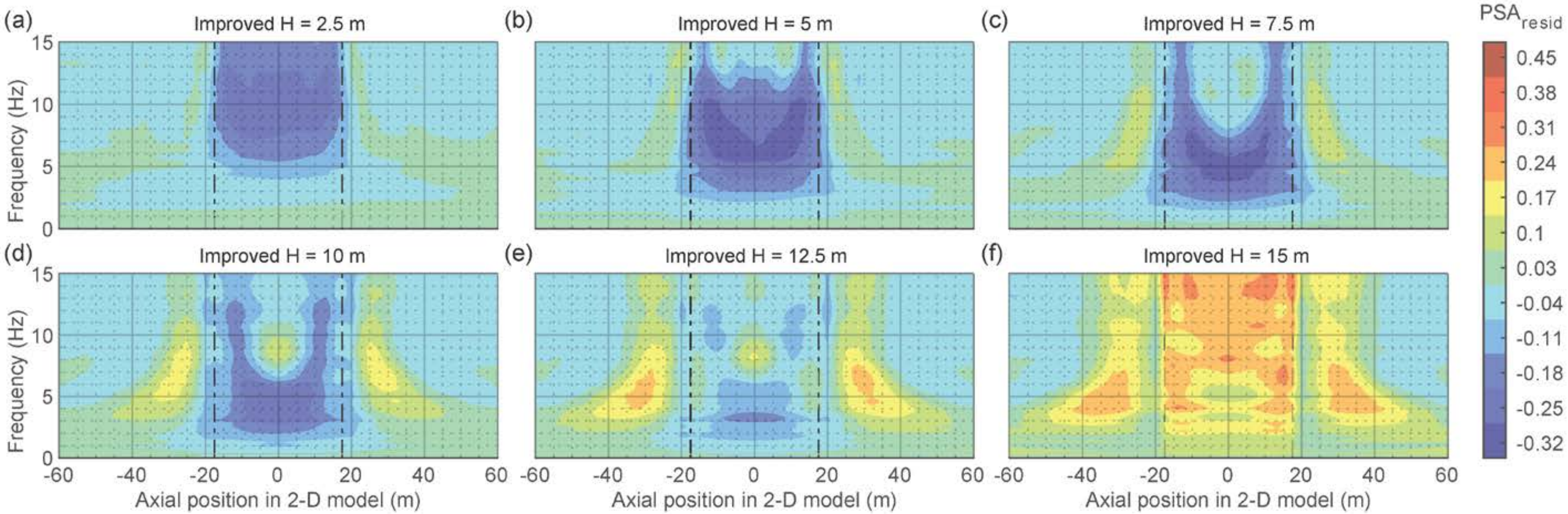
PSA_{resid} calculated considering a densified thickness H = 7.5 m with the improved soil conditions:

(a) IC1 (ΔV_S=15%); (b) IC2 (ΔV_S=25%); (c) IC3 (ΔV_S = 35%);
(d) IC4 (ΔV_S = 35-55%); (e) IC5 (ΔV_S = 55-75%); (f) IC6 (ΔV_S = 75-100%).

Part 1 - Influence of ground densification thicknesses (H increasing from 2.5 to 15 m)

$$\mathrm{PSA}_{\mathrm{resid}}(f) = \ln[\mathrm{PSA}_{\mathrm{imp}}(f)] - \ln[\mathrm{PSA}_{\mathrm{unimp}}(f)]$$

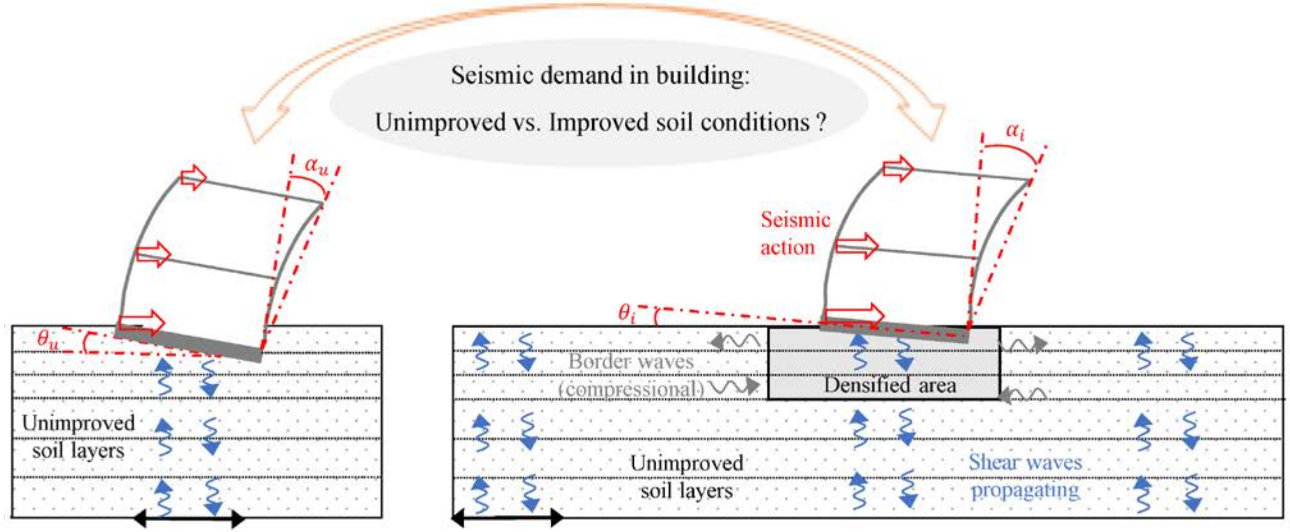
$\mathrm{PSA}_{\mathrm{resid}} > 0$: Amplification
$\mathrm{PSA}_{\mathrm{resid}} < 0$: De-amplification



PSA_{resid} calculated using the improved condition IC3 along with:

(a) H = 2.5 m; (b) H = 5 m; (c) H = 7.5 m; (d) H = 10 m; (e) H = 12.5 m; and (f) H = 15 m.

Part 2 – Ground improvement and SSI effects



base ground motions serving as input motions for SSI problem

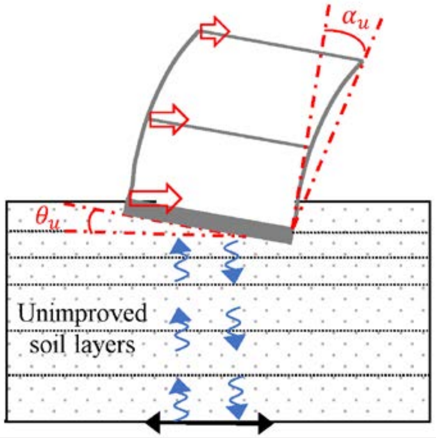
- ➢ <u>Remarks</u>:

✓ The densification and stiffening of bearing soils tend to reduce the foundation displacements while increasing the flexural drift and seismic actions in buildings;

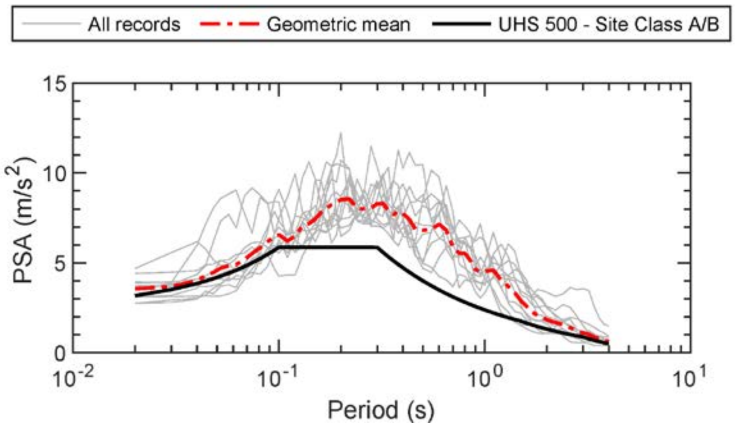
✓ The design of ground improvement requires to meet both geotechnical and structural performance criteria;

✓ The whole soil-foundation-structure system needs to be model to evaluate nonlinear SSI effects.

Part 2 – Hazard-consistent nonlinear SSI problem



Design ground motions for competent bedrock



Design ground motions for rock site class A/B in Christchurch according to NZS1170.5 standards.

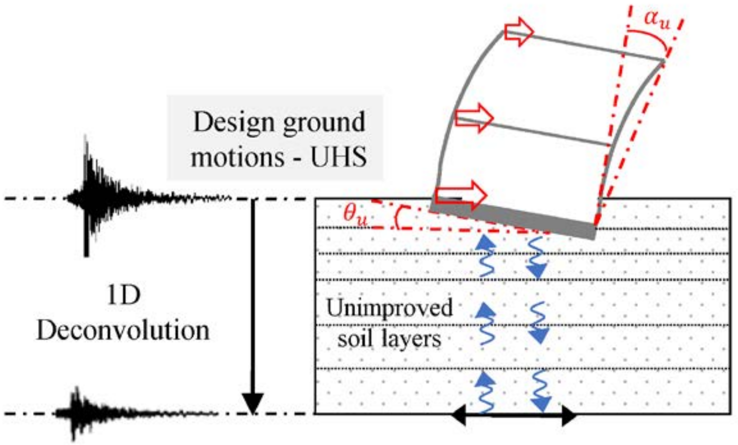
- <u>Some limitations</u>:

✓ The design ground response spectrum provided in NZS1170.5 standard is governed by structural performance factors so that it is not directly applicable for geotechnical design;

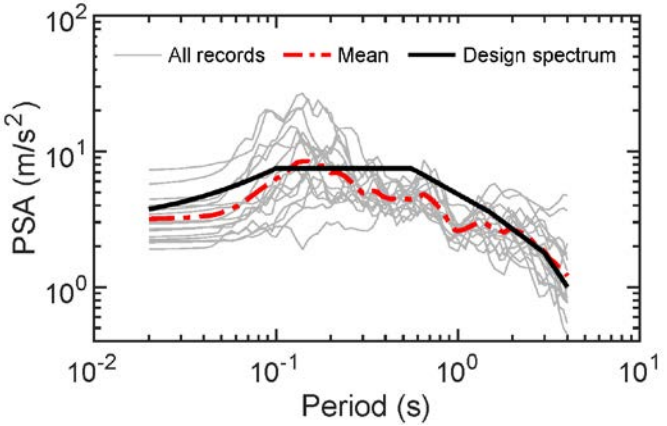
✓ Additional intensity measures other than SA needs to be considered to characterize the geotechnical hazard (e.g., Arias Intensity for liquefaction problems);

✓ Surface ground motions predicted using GRA are underpinned by a range of uncertainties inherent to the model capabilities and its parametrization (e.g., soil damping).

Part 2 – Deconvolution of design ground motions to perform “hazard-consistent” GRA



Site-specific base ground motions serving as input motions



Deconvolved ground motions in competent bedrock

➢ <u>Advantages</u>:

- ✓ The ground motions transmitted at the interface between soil and foundation are consistent with the targeted design spectrum, without carrying on the uncertainties related to ground response models.
- ✓ A recently developed frequency-dependent equivalent linear (FDEL) algorithm has been developed [2] to overcome the recurrent shortcomings when using the EL method to deconvolve strong ground motions in soft soils.

[2] Meite R, Wotherspoon L, McGann CR, Green RA, Hayden C., 2020. An iterative linear procedure using frequency-dependent soil parameters for site response analyses. Soil Dynamics and Earthquake Engineering; 130. https://doi.org/10.1016/j.soildyn.2019.105973.

Conclusive remarks

- ✓ Ground densification has little effects on the spectral accelerations transmitted at the ground surface at low frequencies, up to the fundamental site frequency;
- ✓ At higher frequencies, a densified crust (H ≤ 10 m) overlying soft soil layers tends to de-amplify the spectral accelerations, mostly between 4-10 Hz;
- ✓ The densification of the full depth of liquefiable soil layers results in a substantial amplification of ground motions over a broadband of frequencies, with more than 50% increase compared to the unimproved site response;
- ✓ The soil impedance contrast at the interface between the improved soil and the surrounding unimproved soil leads to a substantial amplification of ground motions up to 25 m away from the edge of the improved zone.
- ✓ The implementation of hazard-consistent nonlinear SSI problems is challenging due to the characterization of the seismic hazard in guidelines, in addition to uncertainties in predicted ground motions using GRA methods.

Thank you