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EXPERIMENTAL STUDY OF CLUSTERED STRUCTURES WITH SFSI

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Abstract

In current seismic design scant attention is given to the flexibility of the supporting soil. For simplicity structures are assumed to be attached to a fixed rigid base. In reality any structure is supported by multiple geological strata of different stiffness and mass. The combination of stiffness and mass gives rise to a fundamental frequency for the site. The response of the structure to earthquake vibration depends on the relationship between the properties of local site and the fundamental frequency of the structure. In the case of closely adjacent structures there is vibrational coupling between the building and the surroundings. Hence, generally no building exists in isolation. In this study the dependency of the building response on the local site will be presented. In case of closely adjacent buildings there is an exchange of energy between the adjacent buildings.

Keywords: Clustered structure interaction, shake table experiment, laminar box

1. Introduction

In current seismic design, damage to structures is tolerated as long as the safety of people is ensured. In the case of buildings or bridge structures plastic deformations at pre-defined locations are permitted such that damage to the whole structure can be controlled, i.e. should the earthquake loading exceeds a certain threshold plastic hinges are developed at those locations. In this so-called capacity design the structures should have the capability to deform plastically prior to collapse.

Over the four decades many studies had been performed on aspects of capacity design of various structural members and structures, e.g. [1]. However, in most design works earthquake-induced interaction between the structure, footing and supporting local soil is hardly considered. Instead, for simplicity, the structure is considered to be fixed to a rigid base. In reality the local supporting soil is not only deformable, the spatial characteristics of the soil can significantly change the dynamic properties of the soil-footing-structure system. This cannot be revealed if a structure with an assumed fixed base is considered. Depending on the soil profile and the characteristics of a vibration source, a soft soil layer over bedrock can transmit or impede the propagation of waves generated by vibrating structures [2,3]. Depending on the condition at the interface between structural footing and the foundation soil the nonlinear soil behaviour can significantly influence the uplift behaviour of the structure [4,5]. In the case of long bridges the difference of the slenderness of adjacent bridge piers will cause unequal bridge pier-soil interaction. This different interaction will lead to relative response between the adjacent bridge segments and thus initiate girder pounding or unseating [6]. In densely populated regions because of the space constraints, buildings are closely located. In many CBDs the buildings have practically no gap in-between. During a strong earthquake interaction between adjacent buildings will likely take place due to different dynamic properties of the neighbouring buildings. Interaction will also take place between the buildings through their common foundation soil [7]. These influences, resulting from the presence of local soil, are as good as ignored in current convetional seismic design.

Some studies on the interaction between neighbouring structures have been performed. However, they were mainly numerical investigations and the numerical models developed were not validated by experiments. This paper addresses the interaction between two adjacent structures under an earthquake loading. To simulate the local soil, sand in a large laminar box is used. The base excitation is generated by a shake table.

2. Experimental setup

Fig. 1 shows the relative location of the four considered structural models A_1, A_2, A_3 and A_4. All structures have the same surface footing with dimensions of 475 mm x 475 mm. The top mass is kept constant so that under the same acceleration the same inertia will be activated. All models have the same height such that the same slenderness effect, due to the same ratio of the height to the footing width, will be achieved. The difference in the fundamental frequencies of the four model is mainly caused by the selection of different cross-section of the column and by different Young's modulus of the materials used. Table 1 lists the dynamic properties of the models with an assumed fixed base. Models A_3 and A_4 have similar fixed-base fundamental frequencies, while the frequencies of models A_1 and A_2 were not only not similar but also significantly different than those of A_3 and A_4. With this configuration it is anticipated that the influence of the interaction, between the adjacent structures, on the structural and soil response will be mainly determined by the low-frequency structures A_1 and A_2.

To simulate the local site a laminar box of the size of 2 m x 2 m x 2 m was used. Fig. 2 shows the structural models in the laminar box. In order to provide the same conditions, i.e. in terms of the ground excitation and the sand properties, all four models were placed in the box simultaneously. At the footings an accelerometer is placed next to the column as indicated by an open rectangle in Fig. 1. At the top of each structure an accelerometer was attached to measure the horizontal accelerations induced by the ground shaking. To detect the interaction between the adjacent structures two laser displacement tranducers were installed to measure the vertical surface displacement of the sand surface at the location between the structures A_1 and A_3 as well as A_2 and A_4, i.e. L1 and L2, respectively.

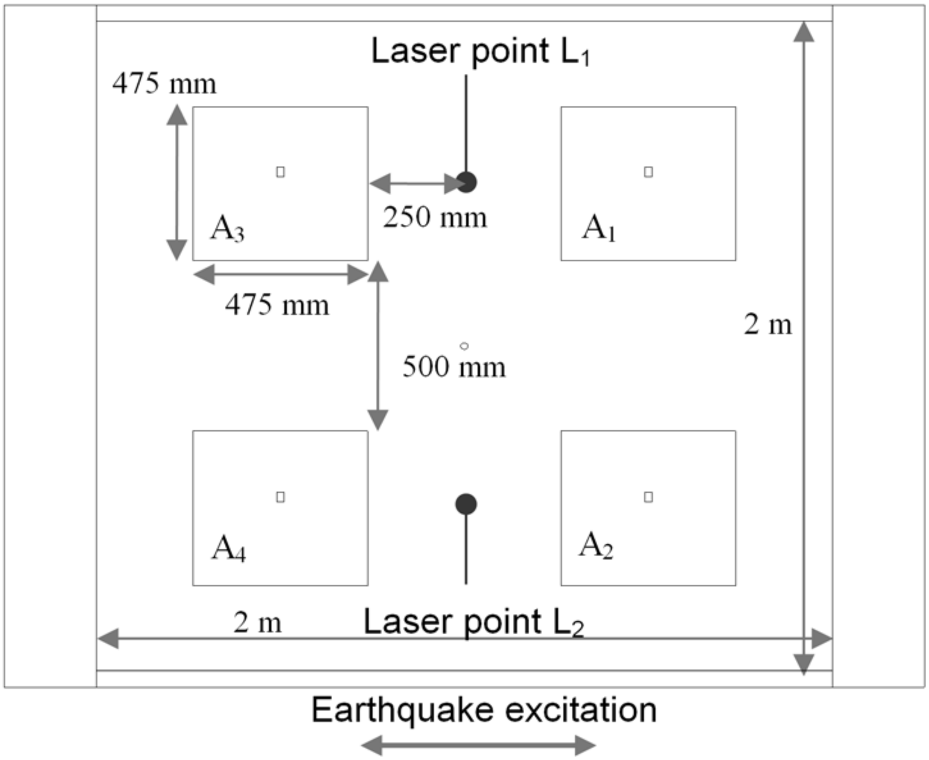

Fig. 1 – Relative location of the structures considered (top view)

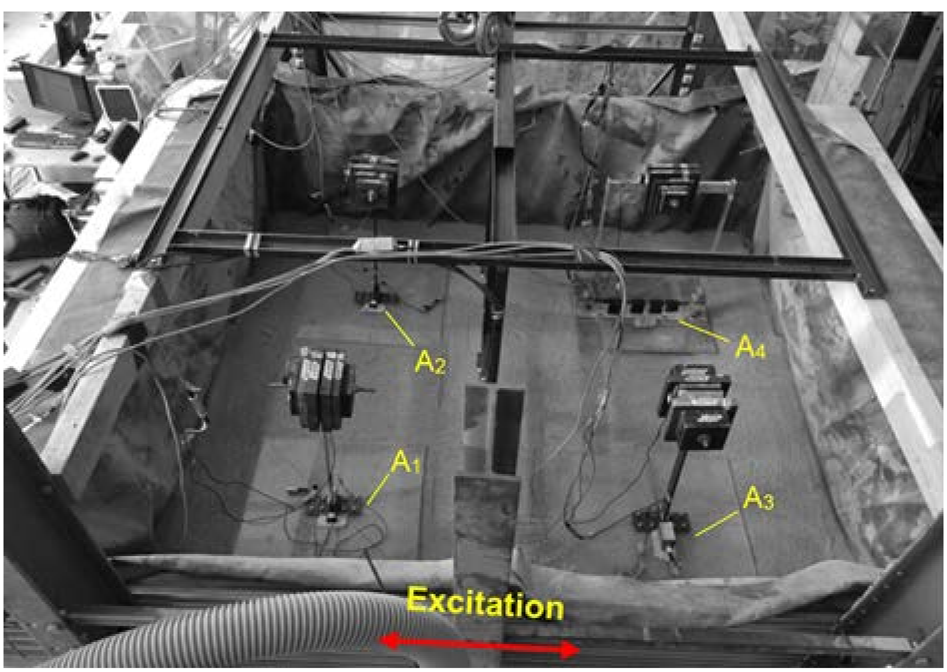

Fig. 2 – Experimental set up of four different structural models A1, A2, A3 and A4

Table 1 – Dynamic properties of the considered models with an assumed fixed base

Model	f (Hz)	T (s)	ξ (%)
A_1	0.59	1.71	0.43%
A_2	1.18	0.85	0.40%
A_3	2.53	0.40	0.89%
A_4	2.77	0.36	0.78%

The ground motions were stochastically simulated based on a Japanese design spectrum for hard soil condition [9,10]. Fig. 3 shows the response spectrum of the applied ground acceleartion (dashed line) and scaled design spectrum (solid line) for a damping ratio ξ of 5%. The vertical dashed lines indicate the fundamental period location of the structures with an assumed fixed base. Although the structures considered in the experiment were supported by sand, i.e. were not fixed to an assumed rigid base, the spectrum value at those locations still provide an indication of the strength of the reaction of the structures. With a fixed base assumption it is anticipated that the two stiff structures A_3 and A_4 will experience the strongest excitation.

Fig. 4 shows the time history of the ground motions with a peak ground acceleration (PGA) of 0.79 g. The shake table is displacement controlled with a maximum stroke of ± 120 mm. The corresponding ground displacements were derived by double integration of the acceleration time history. The peak ground displacement was larger than the maximum stroke, thus it was decided to scale down the ground displacement and the duration of the excitation by a factor of four and two, respectively. Consequently, the duration of the ground acceleration was 50% shorter, while the PGA of the scaled excitation remained the same.

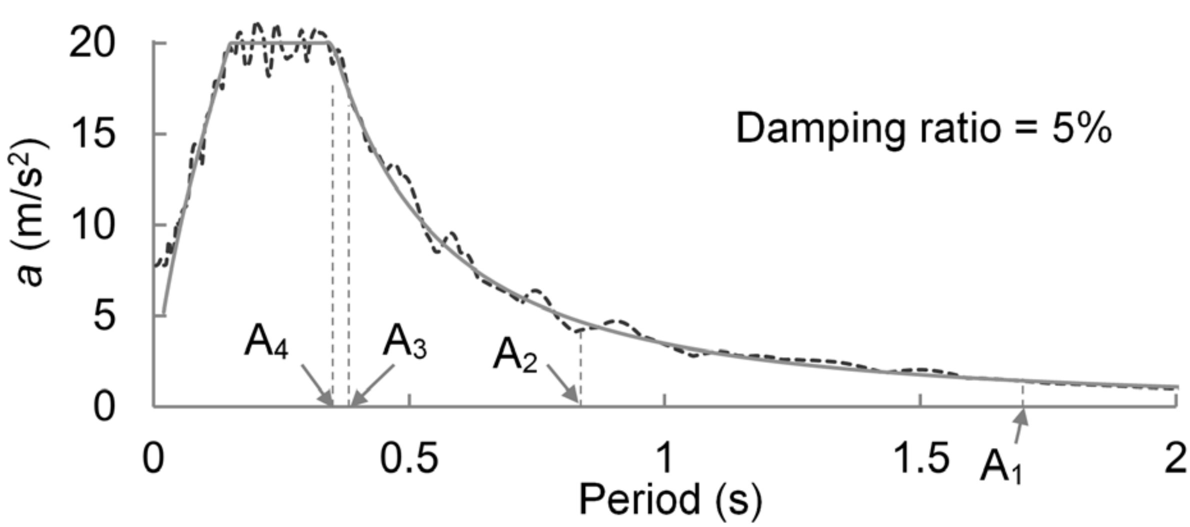

Fig. 3 – Response spectrum of the simulated ground motions and Japanese design spectrum

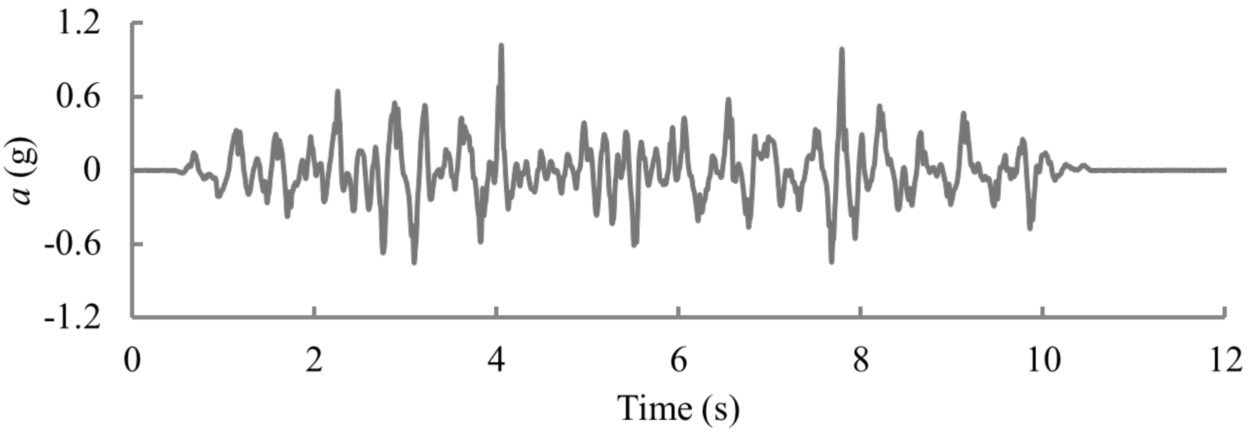

Fig. 4 – Applied ground acceleration

3. Results and discussion

Fig. 5 shows the horizontal acceleration at the top of the flexible and stiff structures A_2 and A_4, respectively (see also Fig. 2 and Table 1). The influence of the local soil can be clearly seen. If a fixed base is assumed, the maximum response of the structures can be estimated from the corresponding response spectrum displayed in Fig. 4, i.e. the maximum response of the stiffer structure A_4 is almost four times larger than that of the flexible structure A_2. In contrast, the experiment results show that the maximum response of the stiff structure A_4 (0.65 g) is only 18% larger than that of the flexible structure A_2 (0.55 g).

A similar effect of local soil on the structural response of the structures A_1 and A_3 can be observed in Fig. 6. If a fixed-base structures is assumed, the stiff structure A_3 will experience much stronger response to the ground excitation than that of the flexible structure A_1 (see Fig. 4). Fig. 6 shows, in contrast, that both structures experience almost the same effect of the excitation. The maximum acceleration at the top of the stiff and flexible structures A_3 and A_1 is 0.99 g and 0.89 g, respectively (Table 2). The results clearly show that neglect of the local soil effect will lead to unrealistic response that will have a significant consequence if used for structural design.

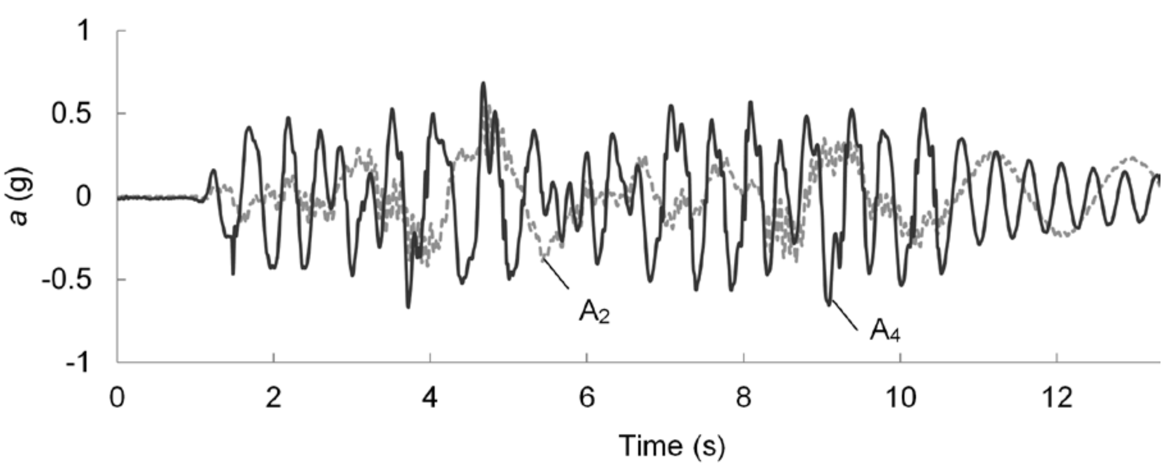

Fig. 5 – Horizontal acceleration at the top of model A_2 and A_4

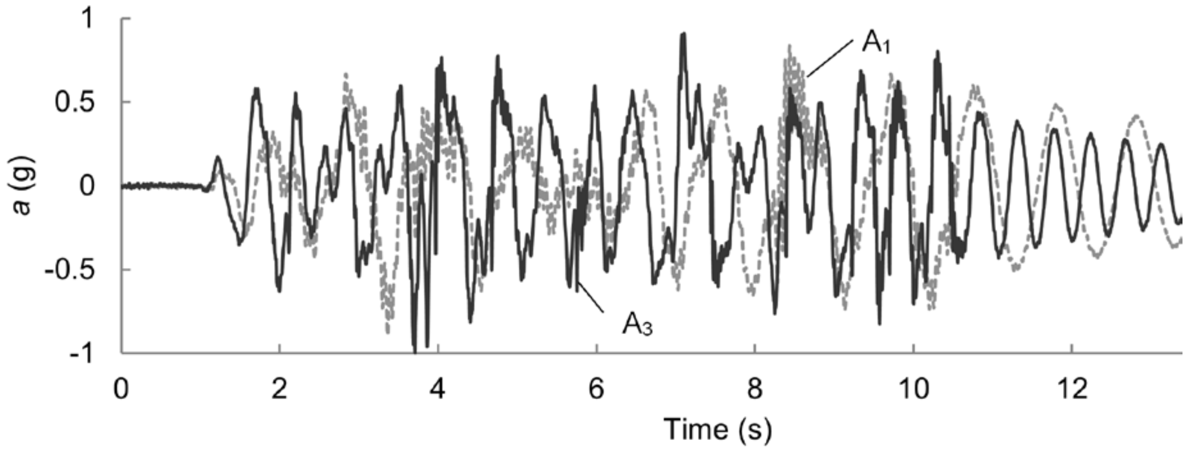

Fig. 6 – Horizontal acceleration at the top of model A_1 and A_3

Table 1 – Summary of maximum horiziontal acceleration at the top of models

	A_1	A_3	A_2	A_4
a_{Max} (g)	0.89	0.99	0.55	0.65

Fig. 7 shows the consequence of the interaction between the neighboring structures. The development of the vertical displacement at the soil surface at the locations L_1 and L_2 is clearly influenced by propagating waves between the participating adjacent structures. The locations of L_1 and L_2 can be seen in Fig. 1. The fundamental frequencies of the structures with an assumed fixed base indicate that the structures A_1 and A_3 have a larger frequency difference of 1.94 Hz than that of A_2 and A_4 (1.59 Hz). Since the local supporting soil can be assumed to be the same spatially, the change in the spreading waves is likely caused by the different interaction between the soil-footing-structure interactions. This results from the stiffness contrast of the participating adjacent structures. The residual soil settlements at L_1 and L_2 locations are 6.4 mm and 4.6 mm, respectively. For L_1, the maximum accelerations of adjacent structures (A1 and A3) are larger than those of L_2. Therefore, due to the structure-soil-adjacent structure interaction (SSSI), the residual soil settlement at L_1 is 39% larger than that at L_2.

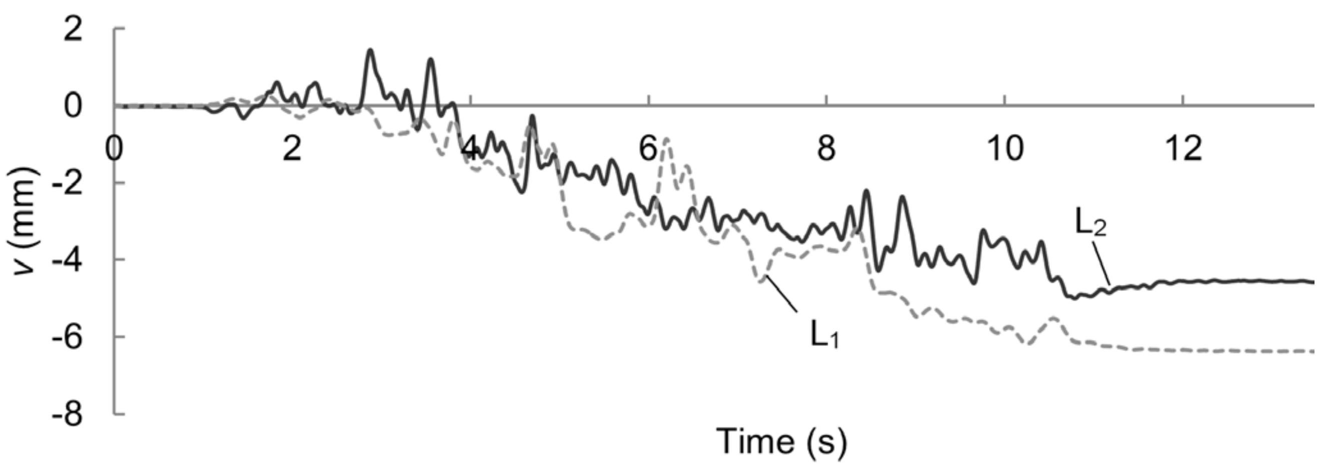

Fig. 7 – Effect of SSSI on ground settlement at L_1 and L_2 locations

4. Conclusions

This paper addresses the influence of local soil on the response of closely adjacent structures. Four structural models, with the same mass and footing on the same local soil, was considered. The difference of the fundamental frequencies is caused only by the different bending stiffness of the columns. The ground motions were simulated stochastically based on a Japanese design spectrum for hard soil condition. The local soil is represented by sand in a large laminar box of 2 m x 2 m x 2m.

The shake table experiments reveal

1. Local soil can significantly alter the response of structures from that of structures with the conventional assumption of fixed base.
2. The response of adjacent structures depends not only on the dynamic properties of the soil-footing-structure system and soil-footing-structure interaction, but also clearly on the structure-soil-adjacent structure interaction (SSSI).
3. In the cases considered, a larger contrast of the dynamic properties of adjacent structures will likely cause stronger SSSI effect.

4. Acknowledgements

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