Real-scale vibration experiments and numerical study of a steel frame structure on a shallow foundations

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OVERVIEW

Dynamic Soil-Structure-Interaction (DSSI) is an important design aspect when considering structural response under dynamic loading. An experimental campaign has been conducted to provide deeper insight into the DSSI phenomena. The test set up consists of a steel frame structure founded on a shallow foundation, which was subjected to forced vibrations. Studying these phenomena requires the consideration of both structural and ground conditions as well as their interaction, which make the study challenging. Finite-Element (FE) modelling is the most accurate tool to study the DSSI phenomena in the time domain, but many computational challenges need to be addressed. Within this context, this study presents three-dimensional (3D) FE analyses, modelling the considered experiments and focusing on modelling the soil-foundation contact imperfections.

EXPERIMENTAL CAMPAIGN

The field testing involved real scale tests of a prototype structure (EUROPROTEAS) that were carried out by the Aristotle University of Thessaloniki research team in collaboration with Imperial College London, under a Transnational Access User Agreement funded by SERA (Seismology and Earthquake Engineering Research Infrastructure Alliance for Europe). EUROPROTEAS (Figure 1a) is a symmetric structure which consists of a reinforced concrete foundation (9Mgr), four QHS steel columns, reinforced concrete top mass (18Mgr) and X-bracing system at all four sides. The structure is founded at the centre of the Euroseistest valley in Northern Greece, whose geologic and geotechnical characteristics are well established by previous studies (Pitilakis et al., 1999; Pitilakis et al., 2018). The shallow layers consist mostly of silty sand of very low stiffness, a condition that accentuates the SSI effects.

During the experiments, ample instrumentation (Figure 1b and c) recorded the soil and structural motion, allowing the detailed examination of the structural response and the thorough investigation of the soil response.

The examined structure was exposed to forced vibration tests, amongst others, during which sinusoidal forces of different frequencies and magnitudes were applied (Figure 2) by a vibrator. Different mass of plates (A,B,C,D) could be placed on the vibrator, a configuration that allows the application of different force magnitudes for the same frequency.

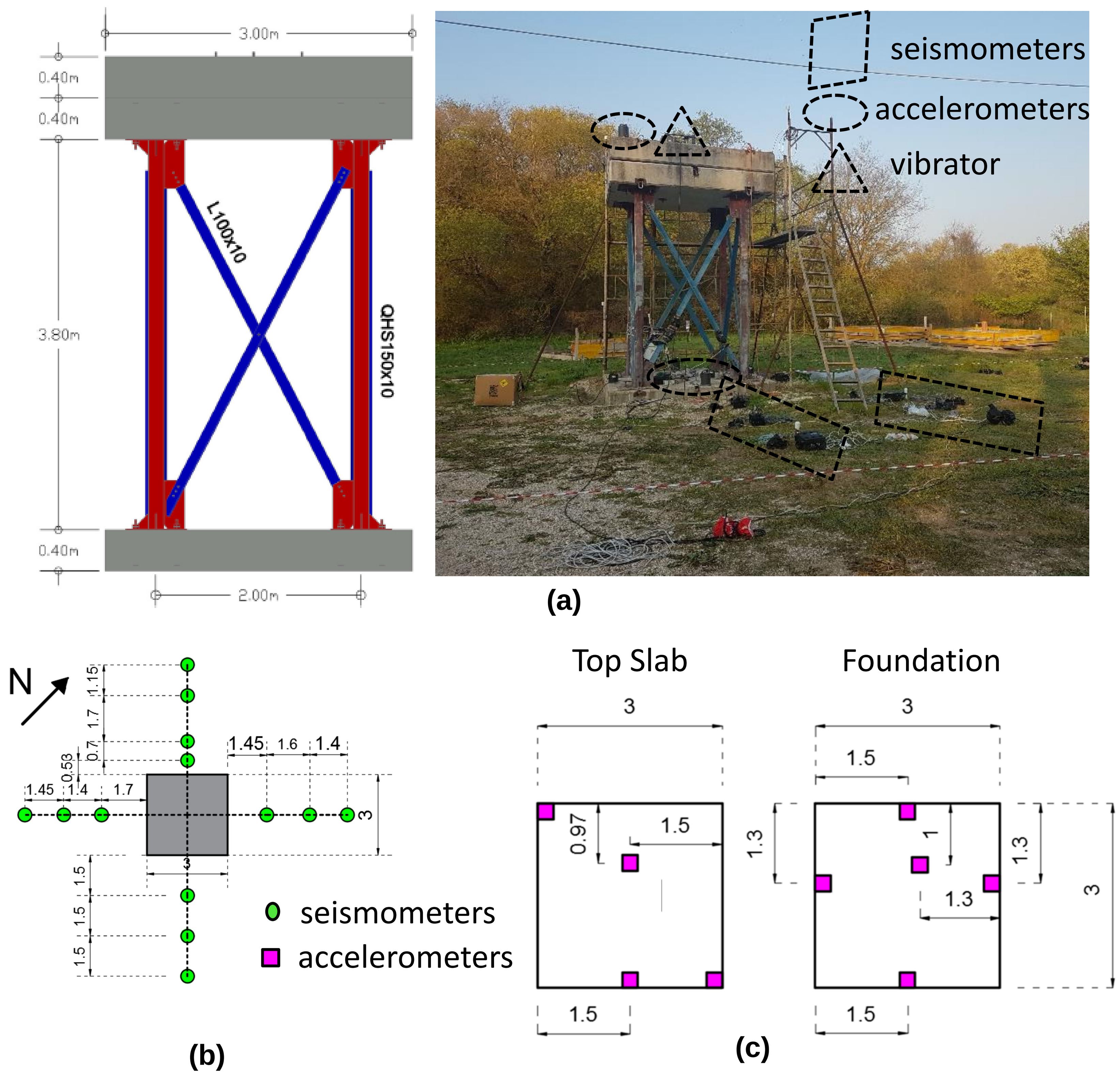

Figure 1: Experimental set up: (a) structure, (b) soil instrument configuration in plan view, (c) structure instrument configuration in plan view

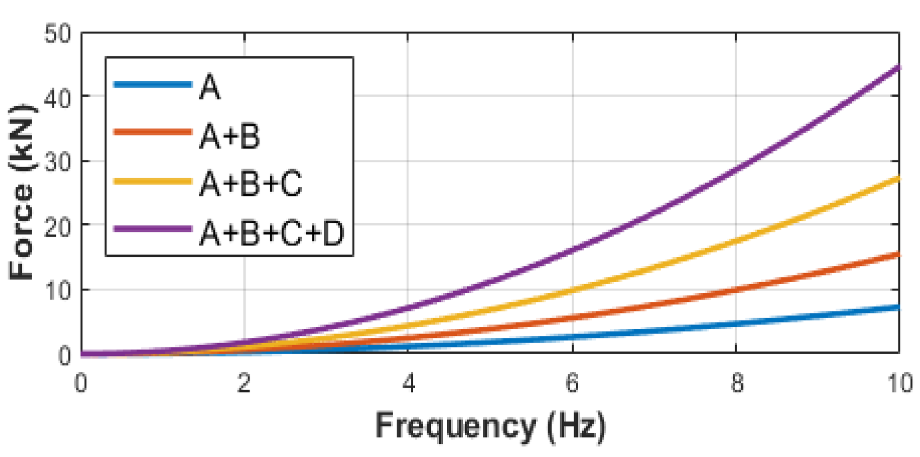

Figure 2: Force magnitudes and frequencies that can be applied by the vibrator.

DATA INTERPRETATION

Figure 3 shows the variation of the recorded top slab maximum accelerations, normalized by the applied force, recorded during the 4 series of forced vibration tests where different plates were placed on the vibrator. It can be observed that the natural frequency of the same soil-structure system, identified by the main peak, varies between 2.77 and 3.5Hz, corresponding to the largest (masses A+B+C+D) and smallest (mass A) applied forces respectively. The latter is an evidence of non-linear behaviour of the system which stems from soil non-linearity and interface non-linearity. The dominant non-linear mechanism is the latter one, which is attributed to the fact that for larger applied forces, the detachment of the base slab from the foundation soil is more pronounced and more rocking takes place, making the DSSI system more flexible.

The most important DSSI effect is the decrease of the natural frequency of the soil-structure systems in comparison with the fixed base structure. Considering that the fixed-base natural frequency is around 9Hz (Pitilakis et. al 2018), the period elongation is around 3, showing the necessity of considering the structure, foundation and soil together in numerical studies.

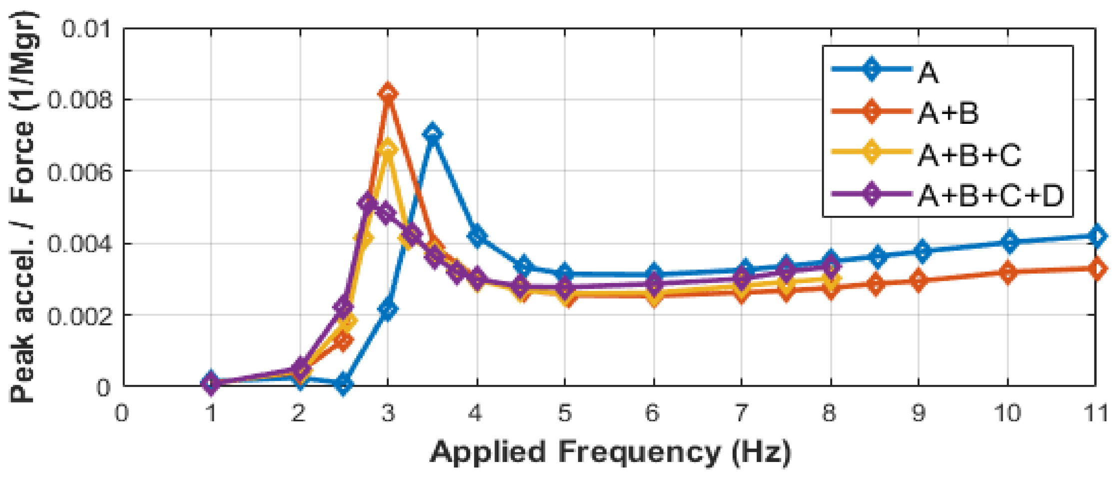

Figure 3: Normalized accelerations recorded on the top slab at each applied frequency. Results from four series of forced vibration tests

NUMERICAL MODEL AND RESULTS

Figure 4 presents the 3D FE model, including dimensions and boundary conditions. Exploiting the symmetry of the structure, only half of the problem is modelled. The lower edges of the soil domain are fixed, the nodes at the plane of symmetry are fixed out-of plane, while dashpots are applied on the remaining boundary nodes of the soil domain. The input motion is applied at the central node of the top slab in terms of displacements, at 5Hz frequency, which are interpreted from the experimental data. A particular focus is on the soil-foundation modelling, where zero-cohesion elastoplastic interface elements are placed in order to allow uplifting and sliding of the foundation relative to the soil beneath. In addition, imperfections at the interface are taken into account by simulating areas with zero contact (gaps) and initial opening of 1mm, between the foundation and the soil.

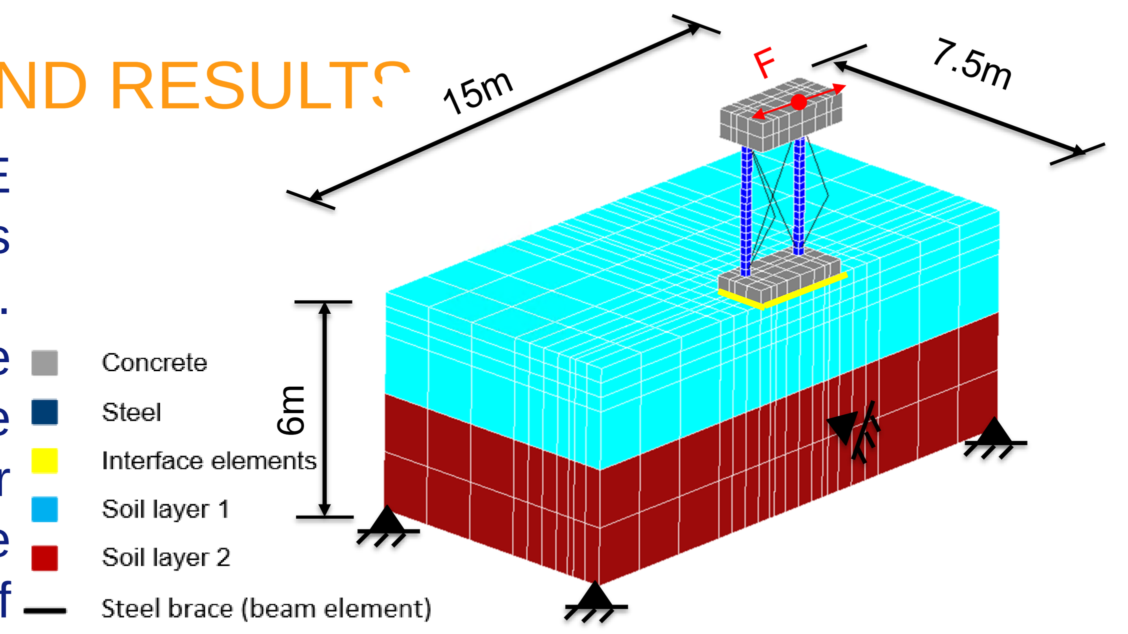

Figure 4: Numerical model and boundary conditions

The numerical analyses are carried out using the Imperial College Finite Element Program (ICFEP) (Potts & Zdravković, 1999). Figure 5 compares recorded and numerical results at the positions of the central top and base slab instruments, as well as the soil instrument at 1.2m North from the base slab. It can be seen that the interface imperfections play a significant role in transferring the motion from the foundation to the soil and makes it clear that special attention must be exercised when modelling shallow foundations that are not in full adhesion with the soil.

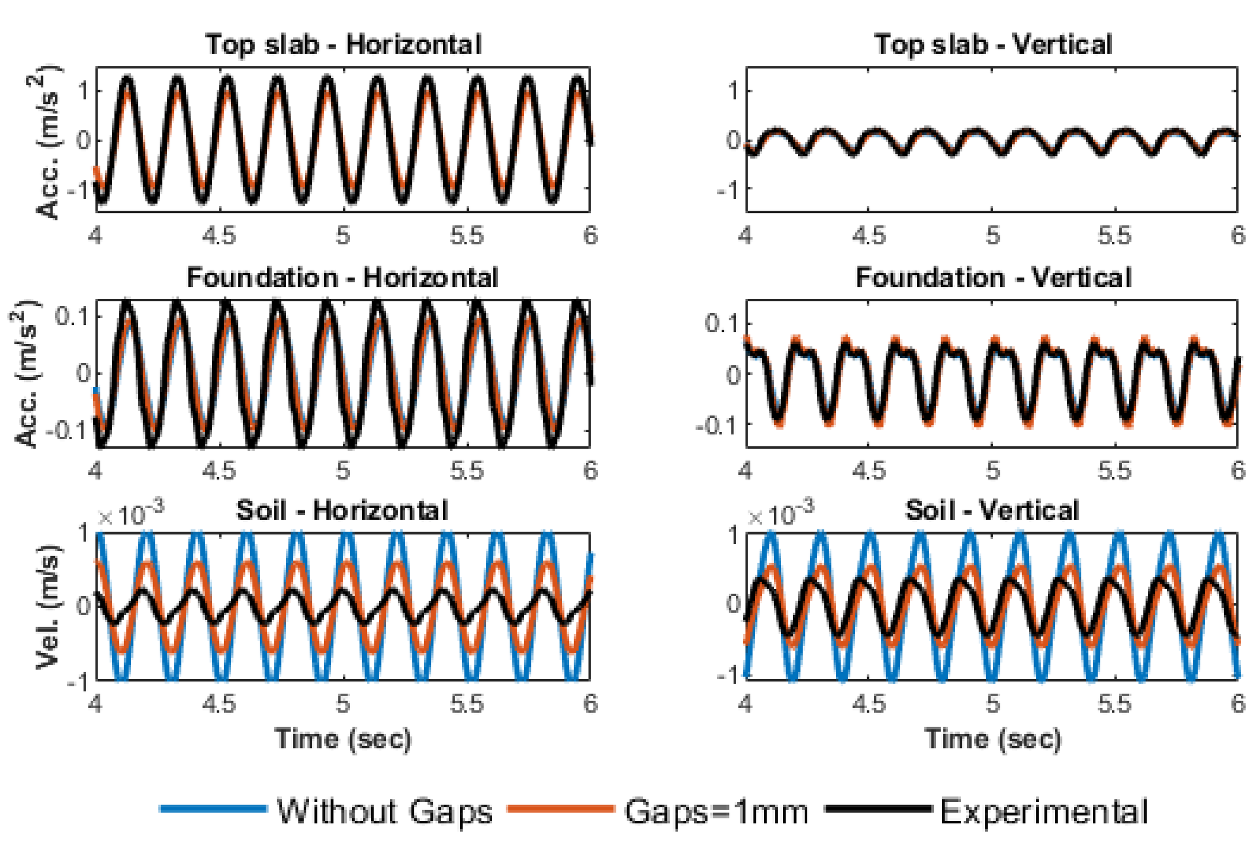

Figure 5: Numerical results

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