Abstract

Performance of drains in earthquake-induced liquefaction mitigation under new and existing buildings

Damage in buildings documented after recent earthquake-induced liquefaction events emphasises the importance of improving vulnerable regions using countermeasure techniques. Further investigations are required to evaluate the performance of currently available mitigation techniques. Vertical drains are an effective countermeasure technique, extensively utilised to reduce damage, as rapid dissipation of excess pore pressures can be achieved in case of liquefaction. However, further research using physical and numerical modelling techniques, centred on the behaviour of drain arrangements below structures is required in order to generate knowledge concerning the issue of their performance in the presence of buildings.

Dynamic centrifuge modelling has been employed in this work to improve understanding related to the performance of drain arrangements in earthquake-induced liquefaction below new and existing structures. The analysis considers the use of recycled material as an alternative to coarse gravel inside the drains and proposes a simplified technique for the accurate simulation of the drain behaviour during soil reconsolidation.

The influence of the foundation bearing pressure as an important factor in the performance of the drain arrangements was observed during and after the shaking, in the evaluation of a simplified arrangement of vertical drains under new buildings. Excess pore pressures were controlled and rapidly dissipated due to the significant confining pressure exerted by the foundation, enabling lower foundation settlement and great rotational response in the case of a heavy foundation. The “unit cell” and “infinite cell” behaviour of the internal and perimeter drains was accentuated in the presence of the structure.

The performances of different alternatives of rubble brick vertical drain arrangements were evaluated, with a focus on providing an optimal treatment to the vulnerable area below the foundation. Improved control and dissipation of excess pore pressures, including enhanced foundation settlement response were achieved when adding edge drains below the foundation in a 13- vertical drain arrangement, due to the higher area replacement ratio in the soil. Moreover, the lower soil softening generated in the stratum with 17- vertical drain arrangement, enabled a great rotational response of the foundation. Countereffects in the effective

performance of the arrangement of 17 drains were also presented during the reconsolidation stage, as a delay in the flow front arrivals of the external drain rings was registered. The foundation settlement improvement was lower than expected when adding the edge drains below the foundation, due to the bulging effect presented at the top of the drains. The alternative of replacing internal and edge drains utilizing aluminium encased vertical drains below the foundation showed an improved behaviour of the soil principally during dissipation compared to the original arrangement. Improved settlement response was obtained using this variation, together with a consequent greater seismic demand of the foundation due to the effective performance of the edge and internal drains and the greater shear reinforcement provided by the columns. In addition, a comparative analysis in which the 17- vertical drain arrangement and the single rubble brick column that covers the entire foundation footprint were evaluated, highlighted the importance of considering external drain rings in the arrangement, capable of reducing the "infinite cell" behaviour of a single drain during the shaking. The foundation settlement response obtained in all the tests, highlights the relevance of an optimal performance of the arrangement during the shaking, rather than only the soil reconsolidation stage.

Inclined rubble brick drain arrangement around existing buildings was evaluated as a feasible and economical alternative mitigation technique. Excess pore pressures were controlled and easily dissipated below the foundation due to the inclined columns radial proximity in the direction of the structure along the stratum depth. In addition, an improved settlement response of the foundation was obtained compared to that over an arrangement of vertical perimeter drains. A larger rotational response was also attained for the foundation in the case of inclined drains, in response to the relatively lower soil softening. Furthermore, the high-bearing pressure of the foundation significantly influenced the effective performance of the inclined drain arrangement, enabling a lower settlement response compared to a lighter foundation.

A simplified 3D finite element technique was developed using ABAQUS software to simulate principally the dissipation behaviour of a soil considering a drain arrangement below new and existing buildings. This simplified method allows to obtain the adequate permeability of the drain coarse material for an optimal response of the foundation in terms of settlement, becoming a valuable tool for practitioners. The models evaluated using centrifuge methodology were also analysed utilising this technique, thus, the validation of the proposed method was possible. The model calibration was performed by varying the soil stiffness and permeability parameters in order to obtain a correct simulation of the soil during and after the shaking. Accurate simulation of excess pore pressure generation was achieved, particularly for traditional vertical arrangements, in small soil stratums. The constant soil stiffness and permeability during the reconsolidation stage, represent the principal limitation in the correct simulation of the soil behaviour, as a slower rate of soil reconsolidation was obtained after the shaking in the numerical model compared to the physical model. The proposed technique was considered satisfactory as a similar settlement response of the foundation was obtained in both the numerical and physical analyses.

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