Detection of earthquake-induced soil liquefaction in harbours based on changes of the structure vibration modes

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Soil liquefaction usually takes place under conditions of rapid and intense stresses (*e.g.*, earthquakes) in low cohesion soils (*e.g.*, granular) with a high humidity content. Such stresses induce a severe particle relocation and thus a reduction of the effective stress (σ'), which according to Terzaghi's principle (eq.(1)) results in an abrupt increase of pore pressures (u). Moreover, if the decrease of effective stresses is high enough, the soil will behave as a viscous liquid, thus losing its shear resistance.

$$\sigma = \sigma' + u \tag{1}$$

In this regard, harbour and coastal structures such as quays or breakwaters located within areas of high seismicity, present an elevated risk of failure due to liquefaction, since coastal grounds are generally formed by granular, low cohesive materials and the water table is situated close to or above the surface.

However, it should also be taken into account that soil liquefaction is not an automatic and instantaneous process but a continuous one, which requires a certain duration and intensity to completely develop. Therefore, different phases (*i.e.*, no liquefaction, partial liquefaction and total liquefaction) can be distinguished [1] in the process, which would affect the structure in diverse manners. In this sense, modal analysis of structures arises as a very useful and versatile tool for the assessment of failure risk in structures subjected to soil liquefaction. Such technique aims to determine the degree of affection of a structure (and thus the risk of failure) by analysing variations in its vibrational response due to soil liquefaction. In this respect, laboratory scaled tests [1] have demonstrated that natural frequencies of the structure may suffer a strong decrease (up to 50% for total liquefaction), while the damping coefficient might be increased up to 20%.

This research project takes advantage of the aforementioned knowledge in order to develop a methodology for the detection of soil liquefaction in harbours, based on a continuous monitoring of the vibrational response of the structure to be analysed.

For this purpose, pressure transducers and tri-axial accelerometers should be located in different points of the ground and the quay in order to register the real-time variations in pore pressure and vibrational response of the structure. If a sudden increase in pore pressure is detected (*e.g.*, due to an earthquake) the degree of liquefaction will be evaluated by analysing the variations in natural frequencies and damping coefficient of the structure.

To this aim, the registered values will be compared with a catalogue of different liquefaction scenarios elaborated prior to the operational phase by means of a numerical model. In this regard, a modal analysis will be carried out considering the soil-structure system as a simplified Winkler beam model (see Fig. 1).

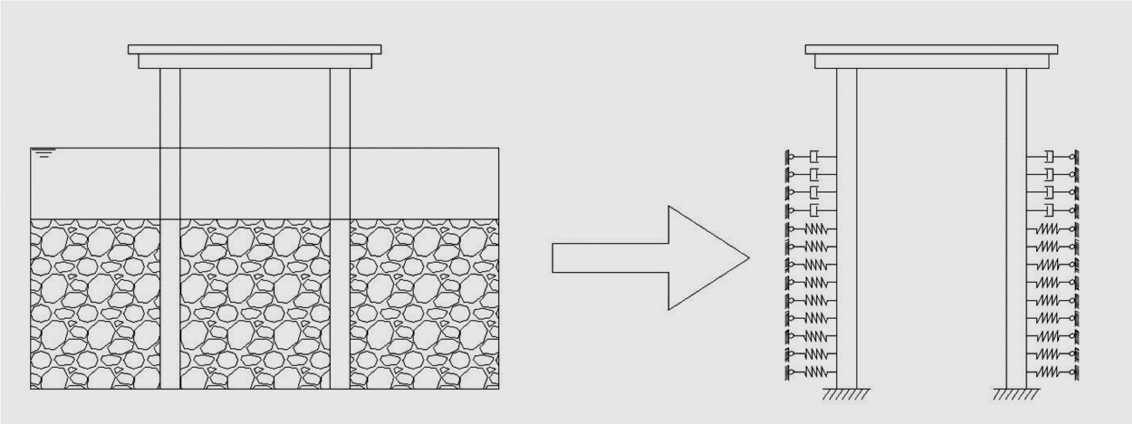

Fig. 1. Simplified Winkler beam model of the soil-structure system

The model reproduces the effect of the soil surrounding the structure as a group of non-linear elastic-plastic springs with variable stiffness (*i.e.*, depending on the liquefaction depth and intensity given by the pressure transducers), while the dissipation effect of the water table is modelled by means of dampers with a certain viscosity [1, 2]. The election of a non-linear model for the springs allows to consider plasticising of the soil, while the structure materials can be considered elastic linear without substantially diminishing the accuracy of the model.

References

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