A multi-material ALE method for vibro-injection pile installation in saturated sand

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ABSTRACT

In geotechnical engineering, the installation processes of the structural elements play an important role because they considerably impact on the surrounding soil and neighboring buildings. This is particularly the case when the installation processes entail dynamic or quasi-static cyclic loading of water-saturated sand, such as, for example, during vibro-injection pile driving. However, typical finite element models in geotechnical practice intended to predict the response of structures simply incorporate the structural elements as if they were wished-in-place and prescribe an assumed material state to the soil.

Vibro-injection piles are used to tie back the base slab of deep excavations in urban area (Fig. 1 above). They consist of a steel pile equipped with injection tubes and a welded collar at the base. When the pile is driven into saturated sand by vibration, the welded collar creates a shaft annulus simultaneously injected with grout (Fig. 1, Detail A). Accordingly, vibro-injection pile installation in saturated sand is generally characterized by multi-material flow with large material deformations, by free surfaces and existing or generated material interfaces, and by the complex coupled behavior of sand and pore water. The numerical simulation of such problems is very challenging and realistic models are yet missing.

In order to overcome the problems associated with the classical Lagrangian and Eulerian approaches used in computational mechanics and fluid dynamics, respectively, a multi-material arbitrary Lagrangian-Eulerian (MMALE) method is currently developed by the authors for the simulation of the grouting process during vibro-installation of piles in sand. The method is an extension of the single-material implicit ALE method proposed by the first author, which is restricted to a single material in each element and each time step [1]. The original MMALE and multi-material Eulerian explicit codes have been developed to model hypervelocity impact, penetration, turbulent flow and material failure [2].

The presentation is concerned with the mathematical formulation and closure of the multi-material flow problem associated with vibro-injection pile installation, as well as with the numerical treatment of the governing equations by an MMALE finite element method. The method applies an operator-split to the governing equations which divides solution into a Lagrangian step, a mesh motion step, and a transport step [3]. The potential presence of multiple materials within a single element increases complexity of the MMALE method (Fig. 1, Detail B). In particular, saturated sand must be modelled as a two-phase material so as to account for consolidation and liquefaction phenomena [4]. Other issues include the determination of the states of the individual materials, the evolution of the volume fractions and porosities, and the discrete interface model for multi-material elements. The method is verified by benchmark tests and by experimental small-scale model tests.

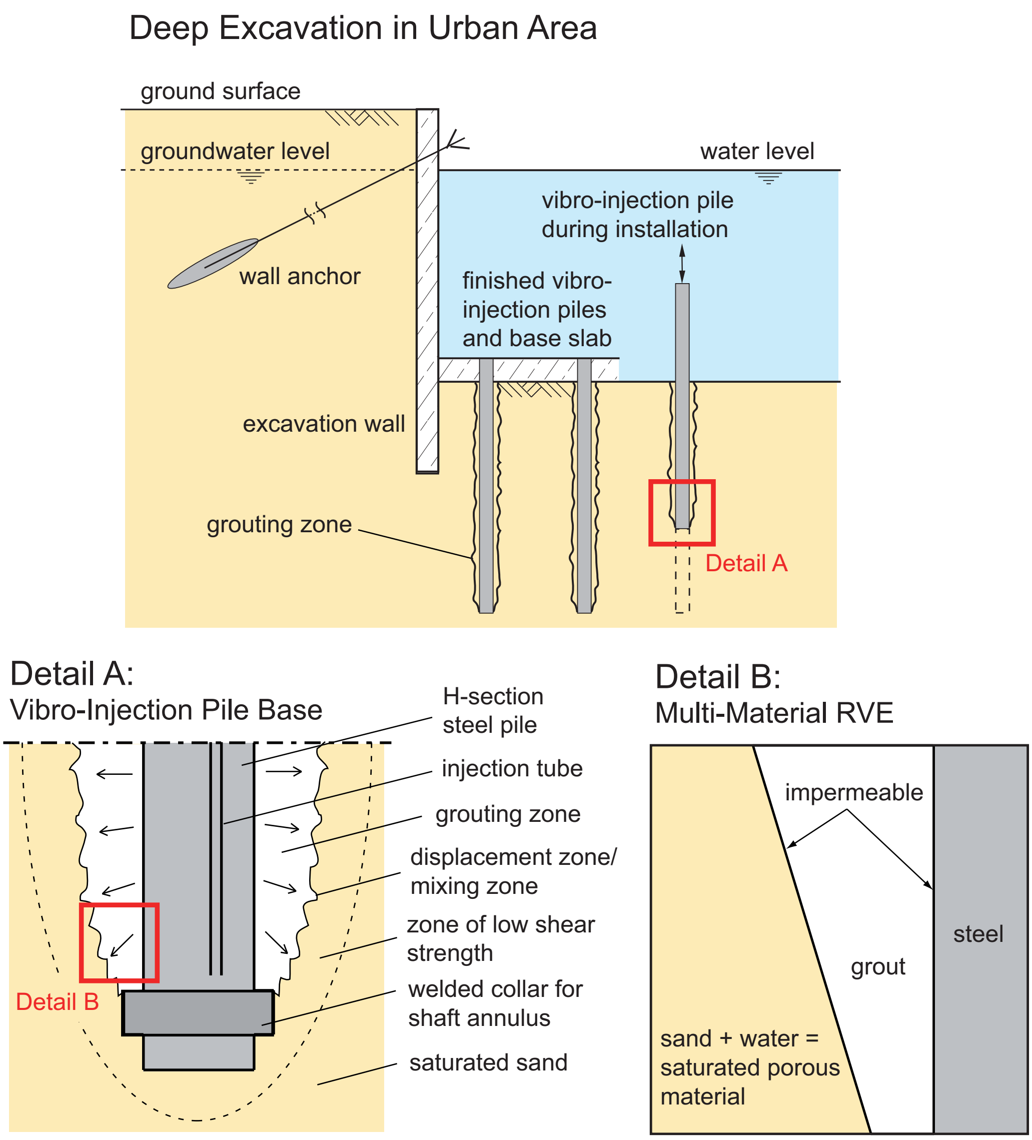

Figure 1: Vibro-Injection Pile Installation in Saturated Sand for a Typical Deep Excavation in Urban Area. Detail A: Phenomenology at the Pile Base. Detail B: Representative Volume Element (RVE).

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