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Validation of material point method for soil fluidisation analysis

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Abstract

The main aim of this paper is to describe and analyse the modelling of vertical column tests that undergo fluidisation by the application of a hydraulic gradient. A recent advancement of the material point method (MPM), allows studying both stationary and non-stationary fluid flow while interacting with the solid phase. The fluidisation initiation and post-fluidisation processes of the soil will be investigated with an advanced MPM formulation (Double Point) in which the behaviour of the solid and the liquid phase is evaluated separately, assigning to each of them a set of material points (MP's). The result of these simulations are compared to analytic solutions and measurements from laboratory experiments. This work is used as a benchmark test for the MPM double point formulation in the Anura3D software and to verify the feasibility of the software for possible future engineering applications.

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Keywords: material point method; fluidisation; liquefaction.

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1. Introduction

Throughout the world, underwater deposits of sand are often susceptible to liquefaction. Soil liquefaction is usually referred to a large loss of shear strength of a saturated cohesion-less soil mass due to an increase in pore water pressure. In areas directly affected by tidal streams and waves, such as coastlines or estuaries, the shore may be built up or degraded by means of cyclic processes. Flow slides in these regions are often the results of liquefaction caused by scouring of the tip of slopes. Flow slides caused by soil liquefaction have in recent years gained a lot of attention due to their abruptness and severity. This paper focuses on a particular case of soil liquefaction, in which the increase of pore water pressure is due to an upward stream in the specimen. This mechanism is also known as fluidisation. A recent enhancement of the material point method (MPM), the so-called double point formulation [1], is evaluating separately the solid and the liquid phase behaviour, assigning to each of them a set of material points (MPs). The two constituents can move with respect to each other and they interact through the drag force. This formulation enables the simulation of flow through porous media, fluidisation, state changing, erosion and sedimentation problems, with a continuum mechanics approach. The analysis and the modelling of vertical column tests that undergo fluidisation by the application of a hydraulic gradient, is presented in this paper.

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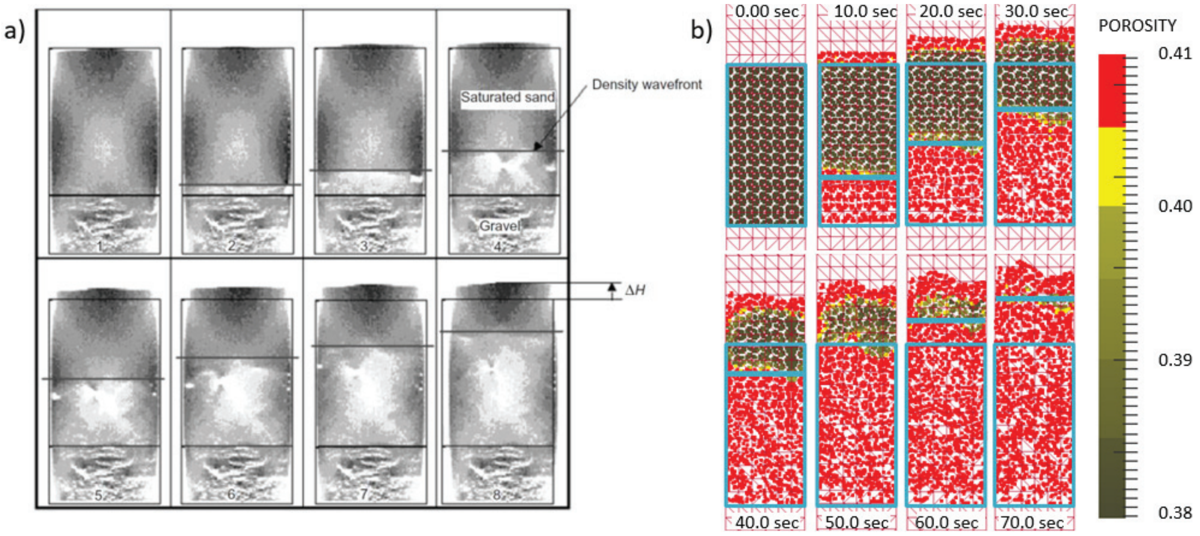

Fig. 1. a) X-ray tomography images from fluidized column experiments; illustration of an upwards propagating rarefaction density wave [2]. b) Density wave propagation visible in MPM fluidisation simulations with initial hydraulic gradient $i = 1.5$; the MPs representing the sand turns red when the porosity exceeds the maximum value n_{max} (fluid state).

First the problem of soil fluidisation and its analytic description is presented. A series of test results from laboratory experiments are then described. Afterwards, the MPM simulation models are analysed. Finally, a comparison of the results is drawn. Conclusions with future developments are provided in the final section.

2. Soil fluidisation process and analytic description

Fluidisation is the process when an upward fluid flow is applied through a sand specimen which maximizes the looseness of the packing. In this paper the upward flow is generated by an hydraulic gradient between an upstream and downstream reservoir. In order to distinguish fluidisation processes from others (i.e. internal erosion, segregation, etc.), hydro dynamically stable beds are chosen. In these beds the mobility of grains is constrained due to a selected grain size distribution and a uniform arrangement [2].

Applying an upward flow to a soil sample, the pressure distribution increases linearly with depth until a critical flow rate is reached which causes fluidisation. Therefore, fluidisation starts at a critical hydraulic gradient, at which the seepage force exerted on the grains by the upward flowing fluid balances their buoyant weight. The critical hydraulic gradient is computed according to Terzaghi's classic theory [3]:

$$i_c = \gamma'/\gamma_w = (G_s - 1)(1 - n) \tag{1}$$

where γ' is the submerged or effective soil weight, γ_w is the water weight, G_s is the specific gravity of the soil and n is the porosity of the soil. It is possible to distinguish several stages in fluidisation problems:

- The soil grains may remain fixed as long as the fluid drag on each soil grain remains low (static equilibrium);
- Increasing the inflow velocity, the upward drag force starts to offset the gravitational forces and the soil expands in volume (heave);
- At the critical hydraulic gradient, the drag forces exactly equal the gravitational forces and the bed will begin to behave like a fluid. At this stage the soil grains are in suspension but their net vertical displacement is equal to zero (incipient fluidisation stage);
- The bulk density of the soil will decrease if the hydraulic gradient is further increased. Segregation will occur and the fluidisation can be classified as particulate or aggregative in behaviour. The particulate behaviour occurs