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Faculty of Civil Engineering and Geosciences
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Delft University of Technology

Real-scale test design of a sand flowslide by MPM slope (in)stability analysis

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Introduction

During a flowslide a large amount of granular material moves within seconds or gradually over hours. The ability to predict flowslides is an important asset for the design, construction, maintenance and safety assessment of submerged slopes; even more so in view of intensifying land use and the impact of sea level change on low-lying coastal areas worldwide. However, these phenomena are not yet well understood. Submerged flowslides take place in a variety of different settings, including for slope angles as low as 1 degree and can cause significant damage to both life and property. *Despite the variety of different movements present in the submerged environment, only slides, debris flow and turbidity currents provide a substantial contribution to gravity driven sediment transport* (Locat et al 2002)*. Flowslides are considered highly complex (multi-phase, multi-physics and multi-scale) and the use of numerical methods for the solution of these problems plays a key role for the optimization and the design of many projects. An integrated numerical solution for the simulation of flowslides from initiation to deposition of sediments, is proposed using the Anura3D MPM software. As validation case study, a sand quarry below ground water level in Belgium was chosen. Here is an overview of the analysis for instabilities in submerged sand slopes which can result in failure triggered by the rapid extraction of sand from the toe of the slope providing insight and knowledge about the causes of flowslides and the possibilities gathered to prevent them.

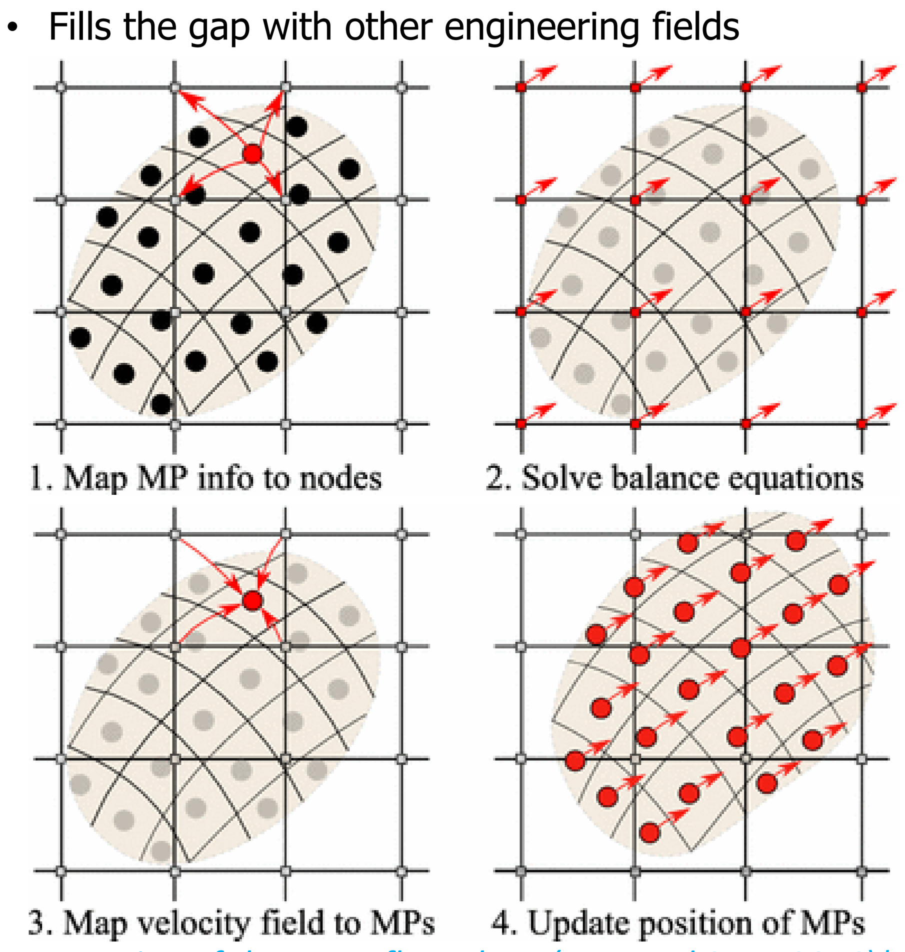
a) Qualitative description of a Flowslide; b) Picture of a typical suction dredger employed in sand quarries below ground water level in Belgium; c) Grain size distribution; d) Data set from CPT test

Material Point Method

In MPM, a body is described by two discretizations: a 'background Eulerian mesh' on which the governing differential equations are cast as in FEM; and a 'Lagrangian cloud of material points' in which all physical information are stored. At every time step it is possible to reset the Eulerian mesh to its initial configuration and update the particle information.

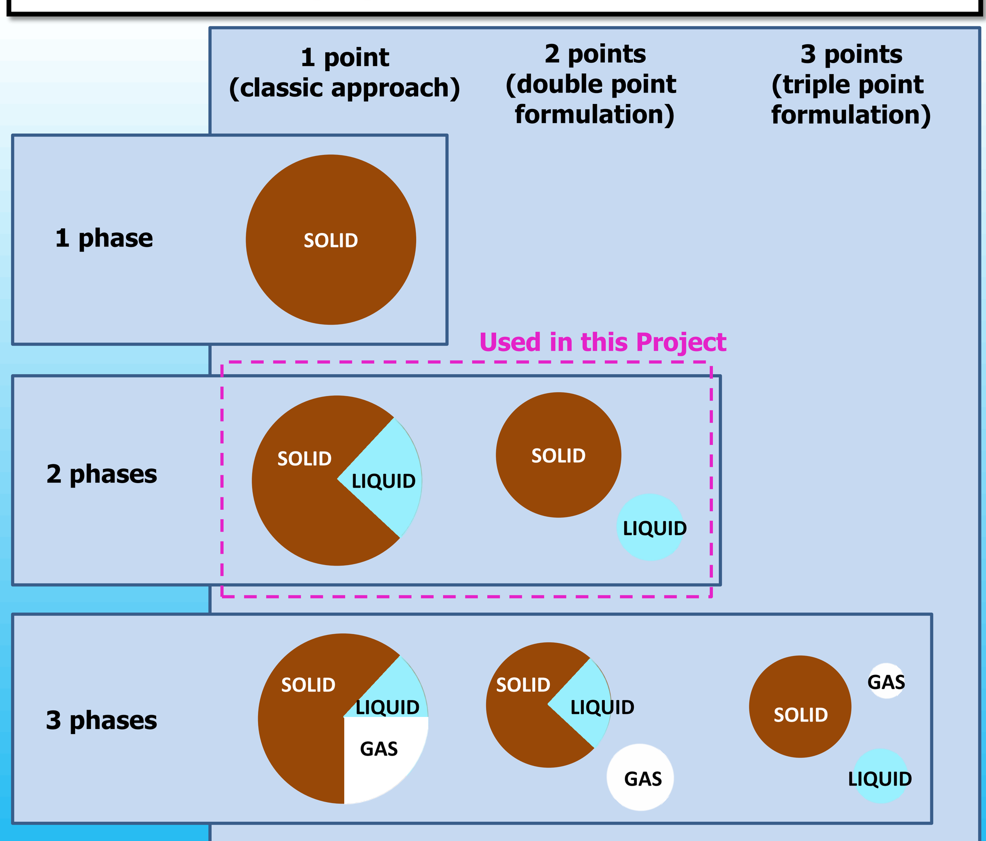
General benefits are:

- Conservation of cultural heritage from FEM
- Large deformation and flow-like problems for history-dependent materials
- Fills the gap with other engineering fields



*Impression of the MPM flow-chart (Fern and Soga 2016)**

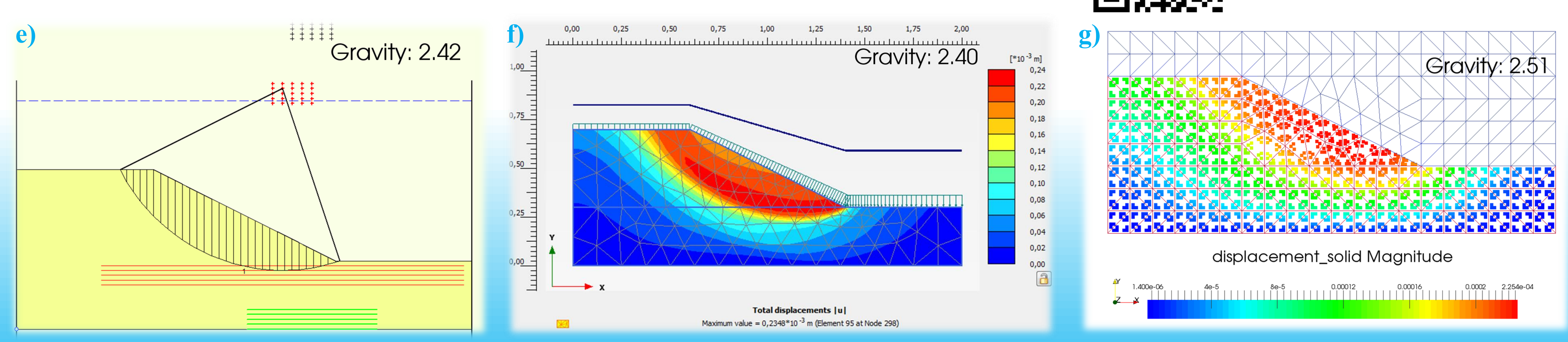
Anura3D
MPM Research Community
Modelling large deformation and soil–water–structure interaction



Available formulations for dry, coupled and fully coupled analysis.

Comparison of available methods

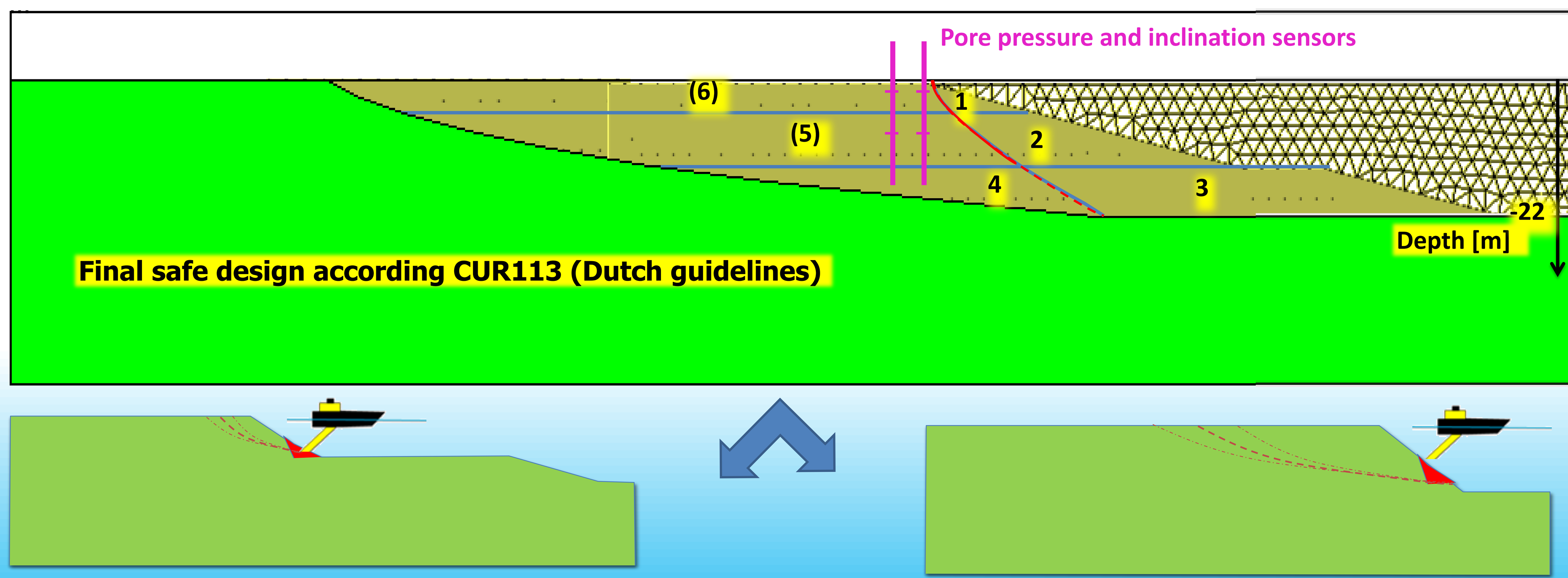
The study of sand flowslides requires an integrated approach of fluid and soil mechanics: soil movement induces turbulent water motion which in turn interacts with the eroding soil surface. Currently, such an integrated approach is lacking. Studies so far mostly rely on empirical approaches that apply to specific circumstances only and involve considerable simplifications. Furthermore, empirical solutions on erosion and sedimentation fall short in sufficiently capturing these interacting processes. As an alternative, physical experiments involve high costs, as scale effects necessitate large test facilities and such tests often only allow predictions for specific projects. This makes the safety assessment of submerged slopes and the development of measures to prevent sand flowslides difficult and expensive. Eurocode7 suggests several approaches, different for every country. This means that not all the slope stability analysis methods are acceptable. For this case study, stability analyses of the sand slopes have been carried out using DGeoStability (Bishop's simplified Method), Plaxis2D (Implicit Finite Element Method) and Anura3D (Explicit Material Point Method). The input parameters are the same for every method and each method gives similar failure mechanisms and geometry. Anura3D also allows the study of the flowslide onset and final geometry. It is possible to watch an MPM slope failure in a centrifuge test simulation at the following QR Code.



e) Bishop's slice method for slope stability analysis; f) Plaxis2D (FEM) simulation with quasistatic loading; g) Anuda3D (MPM) simulation with quasistatic loading.

Real-scale test plan and outcome

Validation and implementation activities are necessary to make the Anura3D MPM software available for civil engineering applications. The results of this real-scale test will increase confidence about the use of MPM for an accurate and site-specific evaluation of the vulnerability of underwater sand slopes to flowslides. Test for monitoring strain and excess pore water pressure propagation from initiation up to deposition of the sediments will be performed. Such a dataset is not available in literature. In order to gain familiarity with current engineering practice, the CUR113 (Dutch guidelines for slope stability in quarries) will be applied. During the transition between the actual geometry and the CUR113 safe design, a steep slope will be excavated. The instability will be triggered by dredging sand at the toe of this steep slope.



Transition from 'actual geometry' to 'real scale test geometry' to 'final geometry'. The range of expected failure mechanisms is visualized at two depths. Failure is expected to be triggered by achieving a fast rate of excavation (loading) on a steep slope.

*REFERENCES: Fern, E. J., Robert, D. J., & Soga, K. (2016). Modeling the Stress-Dilatancy Relationship of Unsaturated Silica Sand in Triaxial Compression Tests. Journal of Geotechnical and Geoenvironmental Engineering
Locat, J., & Lee, H. J. (2002). Submarine landslides: advances and challenges. Canadian Geotechnical Journal

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