QuickAware: A Virtual reality tool for Quick Clay Landslide Hazard Awareness

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Supplementary information 1: Integration of Numerical Simulation of quick clay landslides into Virtual Reality

1. INTRODUCTION

The purpose of this document is providing supplementary information to the main journal paper "QuickAware: A Virtual reality tool for Quick Clay Landslide Hazard Awareness" on how the results of the numerical simulation were imported into Unity. Gjerdrum landslide that was mentioned in the main paper was used in this material as well. A 3D numerical modelling was carried using multiphase solver based on CFD toolkit OpenFOAM® (OpenCFD Ltd 2020). In the following sections a framework showing the integration of numerical simulation results of quick clay landslide into virtual reality was defined.

2. METHODOLOGY

This whole framework can be summarized into four district stages namely preprocessing, numerical simulation, post processing and VR visualization as shown in **Error! Reference source not found.**. Scripts based on python and C# and a visualization tool kit Paraview (Ahrens et al. 2005) were used for pre-processing of the simulation data.

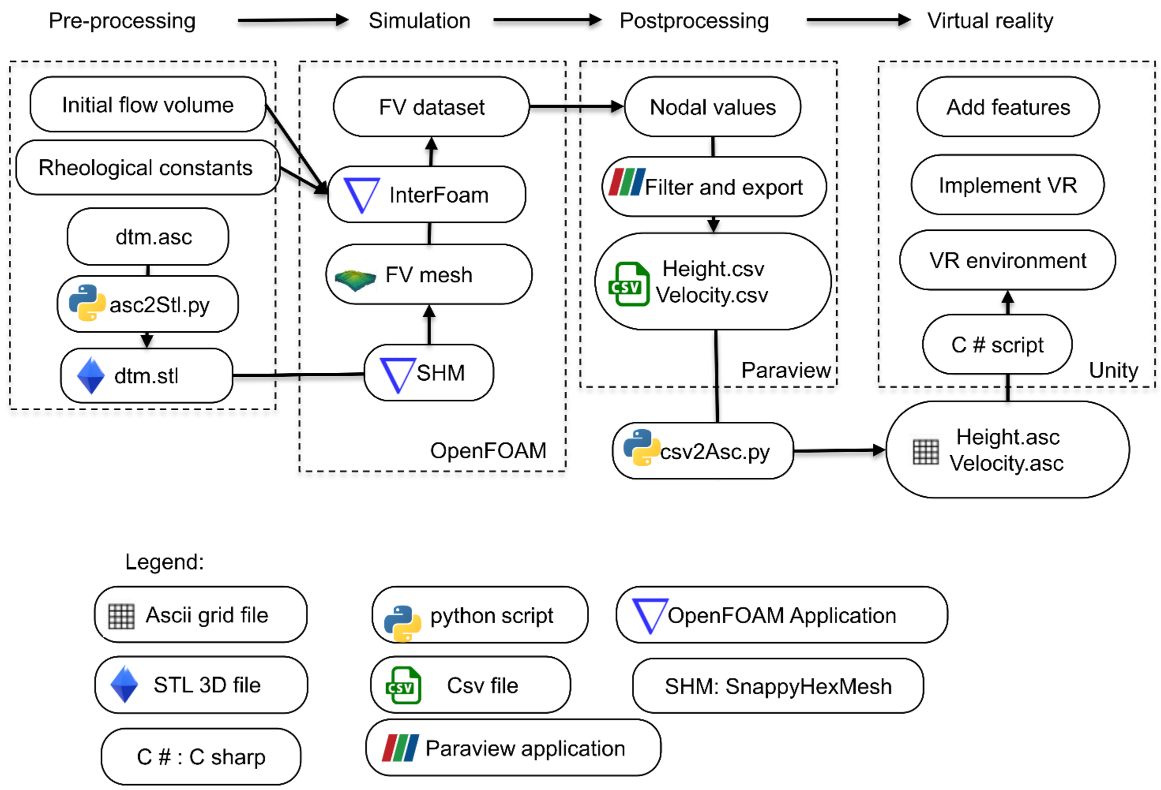

Fig. 1s Overview of the framework

2.1 Pre-processing

The initial step to conduct numerical simulations in OpenFOAM is the computational domain, the topography in case of flow landslides. The topography is mostly available as a digital terrain model (DTM) in GIS formats. The DTM was triangulated and translated into 3D volume by adding side and top walls and stored as a 3D STL file to prepare it for meshing using a python script provided in Rauter et al., (2018) with little modification.. Similarly, the release volume, acting as an initial condition, was stored as STL file. The rheological parameters were prepared from geotechnical investigation results and are discussed latter.

2.2 Numerical simulation

The governing Eq.(1)- Eq.(6) provided in section 3.4.2 A of the main manuscript were solved based on the finite volume method (Eymard et al. 2000). The 3D volume created in the preprocessing stage was spatially discretized by the OpenFOAM meshing utilities to obtain hexagonal finite-volume cells. The temporal domain was split into time steps and the equations were solved in a time-marching manner. The immediate outputs of the simulation are the pressure, velocity, α, and effective viscosity for each finite volume cell at each time step.

2.3 Postprocessing

The results from the numerical simulation were visualized and further processed in ParaView (Ahrens et al. 2005). Paraview is an open-source application for visualization two- and three-dimensional data sets. Paraview interpolates the cell values from the simulation into nodal values. A contour filter utility in paraview traces the interface of the quick clay mud and air. A contour surface of α=0.5 resulted in a collection of coordinates on the interface of the quick clay mud and air and the corresponding velocities. These coordinates and velocities were exported as comma delimited (separated) value (CSV) files. The CSV file formats were then transformed into GIS ASCII grid file formats (.asc) using a python script (see **Error! Reference source not found.**S).

2.4 VR Visualization

We used Unity (Haas 2014) to create a 3D virtual reality environment. The virtual environment consists of the terrain, the landslide, and other features imported into Unity as 3D model objects. A custom C# script was used to import the Ascii grid file formats and partially automate the VR visualization. The Ascii files are the terrain before landslide (i.e. dtm.asc), the mud-air interface surface (i.e. Height.asc) after each time steps and the corresponding velocity (i.e. Velocity.asc) in at each time steps (see **Error! Reference source not found.**). Firstly, the initial terrain was imported to be used as base terrain and the terrains derived from the mud-air interface surface at each time step were also imported and stored as frames. Secondly, to improve the visual quality, the basic terrain and the frames were textured. The velocity files were used for texturing the mud flow. Thirdly, the dynamic nature of the landslide was represented by the animation of the series of the frames. The frame rate in the animation was taken from the timesteps used in the numerical simulation. At this stage, a user can view the dynamic simulation of the landslide in Unity.

3. RESULTS

3.1. Case study area

Gjerdrum quick-clay landslide happened in southwest of Ask, the municipality center of Gjerdrum, (Viken county, Norway) on December 30, 2020. The release area was approximately 120,000 m^2. The deposits had a maximum runout length of about 2 km. The mobilized mass of clay is approximately 1.35 m^3 and about 0.47million m^3 remained over the sliding surface (Penna and Solberg 2021).

For the construction of computational domain, a pre-event and post-event DTM of 0.5m resolution was used. The pre-event DTM was used for the simulation while the post-event DTM was used to set up the initial release volume. The Herschel-Bulkley rheology parameters are taken by correlating with consistency limit tests conducted by Multiconsult (2021) are provided in Table 1.

Table 1. Herschel-Bulkley rheology parameters used in the numerical simulation

Parameter	***τ_y(pa)***	***K(pa)***	***n(-)***	***Density(kg/m^3)***	***μ_e (kg/ms)***
Value	*200*	*50*	*0.34*	*2000*	*$2x10^5$*

3.2. Numerical simulation results

Numerical parameters for OpenFOAM have been chosen such that they do not influence the results, while keeping the solver as stable as possible. Mesh size of D = 2.5m has been used and the simulation duration has been set to 220 s. This duration is sufficient to reach standstill (not observable flow). As presented in **Error! Reference source not found.** and **Error! Reference source not found.**, the simulation significantly captures the deposition well. We suggest that the discrepancy between the observed and simulated results is due to that fact OpenFOAM considers the whole landslide as a dam break problem while in practice quick clay landslide starts retrogressively.

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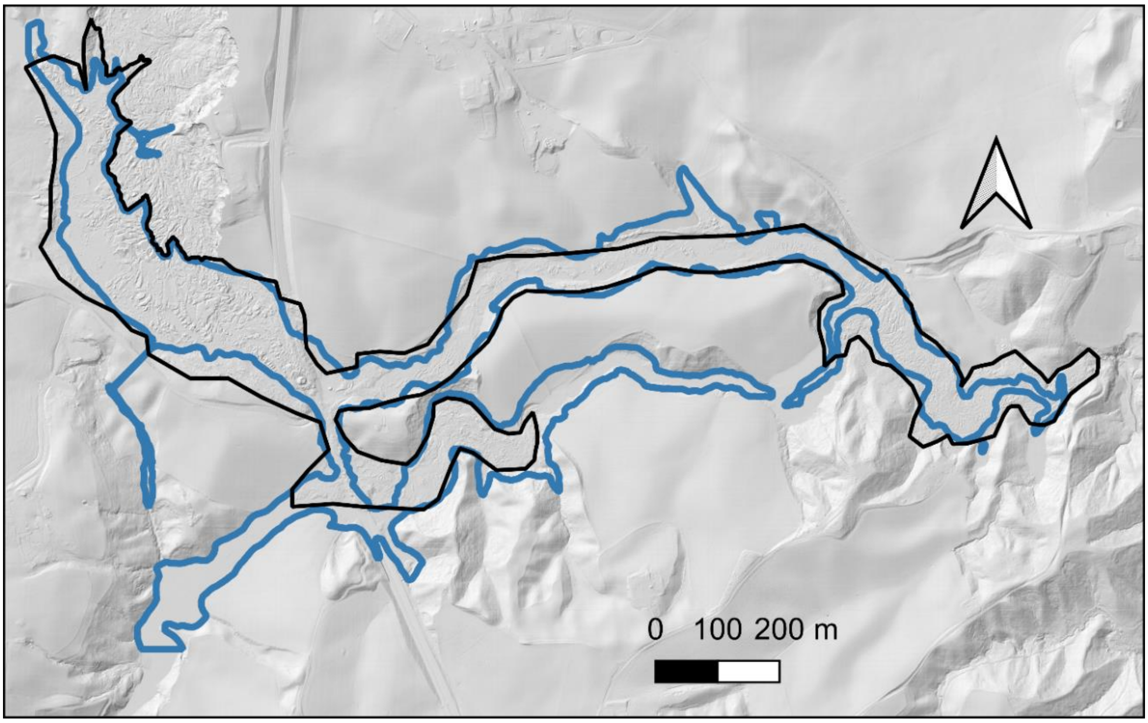

Fig. 2S Final deposition area. The blue line is for the simulation result while the black line is for the observed deposition area.

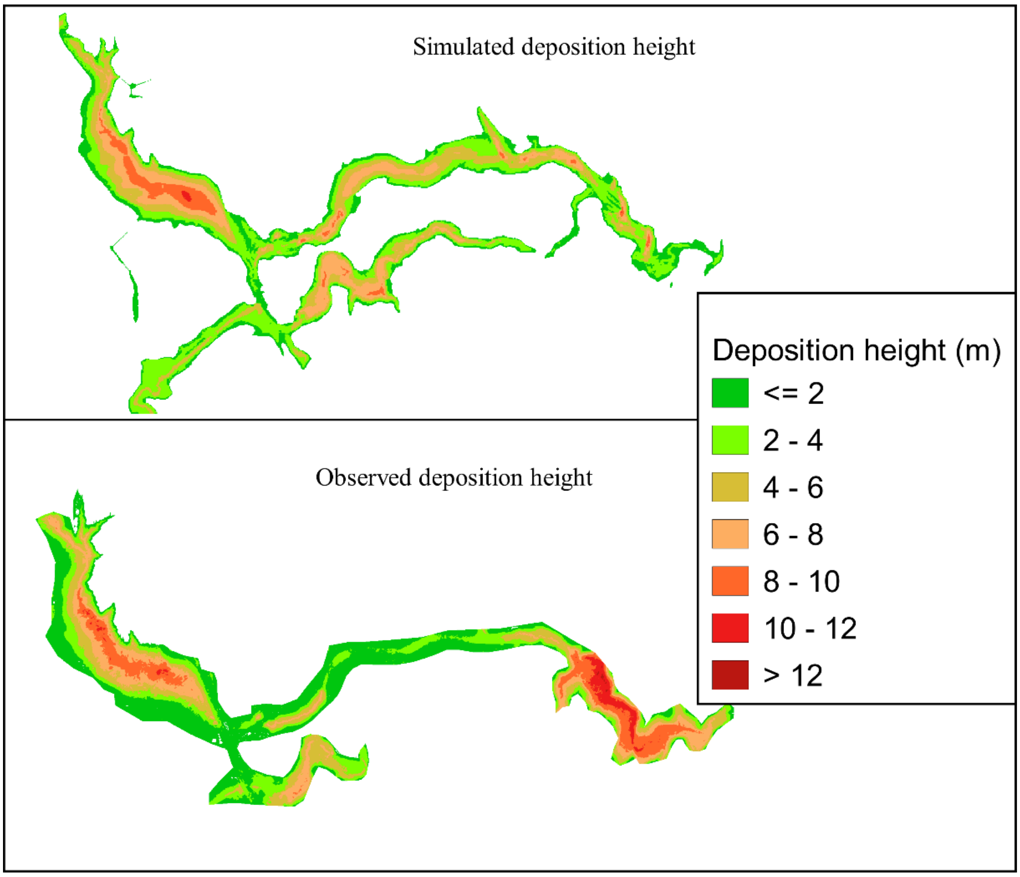

Fig. 3S Final deposition height comparison

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