On the generation of submarine landslide models for Material Point Method simulations through bathymetric data

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Abstract. Submarine landslides are natural phenomena that can cause economic problems and environmental disasters, as the force of the sliding mass can break pipes, interrupting production and destroying whole ecosystems. By simulating these landslides using bathymetric data, one can optimize the design and construction of subsea equipment to minimize its risks. This work aims to create a wizard that, using bathymetric data, guides the engineer through the process of creating a simulation input for the submarine landslide study. The simulator used was developed in-house and uses the material point method to solve continuum mechanics momentum conservation equations for a vast library of constitutive models. The wizard's objective is to streamline numerical parameters by automating and optimizing model choices inherent to the computational method, allowing the engineer to focus on the physical problem rather than the numerical details. Furthermore, it will be possible to configure a vast range of physical parameters, such as the definition of the sliding mass, the constitutive model and its parameters.

Keywords: Submarine landslides, Material point method, Numerical simulation.

1 Introduction

Submarine landslides are mass movements of sediment and rock on the seabed that can be triggered by various factors, including underwater volcanic activity, earthquakes, overpressure and gas hydrates [1]. These landslides can even cause the generation of tsunamis if they displace enough water rapidly. They are natural phenomena and can cause significant economic impacts and environmental disasters, as the force of the sliding mass can cause the rupture of fiber optic submarine communications cables and brake pipelines, interrupting production and destroying whole ecosystems.

Simulating submarine landslides is an important area of research that involves the usage of computational models to understand the dynamics, triggers, and potential impacts of these events. One can optimize the design and construction of subsea equipment to minimize its risks. There are a lot of advantages that come from simulating these submarine landslides, such as risk assessment, which helps to understand the potential risk posed by submarine landslides to infrastructure, to avoid disasters and to develop mitigation strategies [1]. Another advantage is the understanding of triggers, whereby simulating different scenarios, researchers can identify the primary triggers of submarine landslides in specific regions, whether it is sediment instability, seismic activity, or other factors [2]. And finally, landslide simulations allows researchers to explore a wide range of scenarios cost-effectively in a controlled virtual environment, without the need to conduct physical experiments in underwater environments, which can be challenging and expensive.

Computational models simulate submarine landslides using equations that describe the behavior of sediment and rock under different conditions. These models often use principles of fluid dynamics, soil mechanics, and geotechnical engineering. Also, they take into account factors such as the slope of the seabed, sediment properties (e.g., density, strength), water depth, and external triggers like seismic activity or volcanic eruptions.

Submarine landslides are complex problems involving interaction between different phases (like the possible interactions between the soil, the water and offshore infrastructures), contact, large displacements and deformations and nonlinear constitutive models. State-of-the-art softwares focused on numerical simulations normally uses finite element analysis, like COMSOL and ANSYS, which can simulate submarine landslides, but suffers from numerical instabilities like mesh distortion. In addition, their GUI has a broad spectrum of tools that enable the simulation of virtually any problem, which requires its users to have a solid grasp of numerical analysis concepts. The material point method (MPM) [3] is a common alternative that combines the benefits from Lagrangian and Eulerian methods, used for submarine landslides simulations. However, most of the available MPM software does not provide a graphical user interface, such as Anura3D [Community] and Karamelo [5]. Without a GUI, non-experienced engineers can have a hard time exploring the full potential of the tool. And when the solution does have a GUI, like NairnMPM [6], it is not an easy task to adapt it to include the pre- and post-processing necessary to execute submarine landslides simulations.

This work presents a wizard, inside a GUI, that guides engineers through the process of creating, simulating and analyzing submarine landslides. Moreover, we enable engineers without a heavy background in numerical methods to analyze submarine landslides in a fast and intuitive graphical user interface that uses an in-house developed tool, named E-Sub3D.

2 Wizard Overview

The wizard's objective is to streamline numerical parameters by automating and optimizing model choices inherent to the computational method, allowing the engineer to focus on the physical problem rather than the numerical details. The application was developed in Qt/C++ for the forms, windows and widgets and OpenGL to display the bathymetric data.

To simulate such landslides first we need to load bathymetry data into our wizard. The bathymetric information usually comes from text-based ".xyz" files that can contain dozens of millions of points and have sizes in the range of several gigabytes. In some cases, multiple layers of the seabed can be loaded at the same time into our wizard, so the number of points and file sizes can get into the hundreds of millions of points.

The flowchart in Figure1 summarizes the wizard application. First, the user login with his credentials, to have access to saved models from previous simulations and other personal information. Then, he access the create a new model screen, and chooses a name and selects the template for the new model. In the next screen, the bathymetry files are loaded into the application. Also, there are sliders to help the user define the region of interest, which limits the area where the simulation will occur. And last, defines the critical slip surface, which is the region that will slide in the simulation.

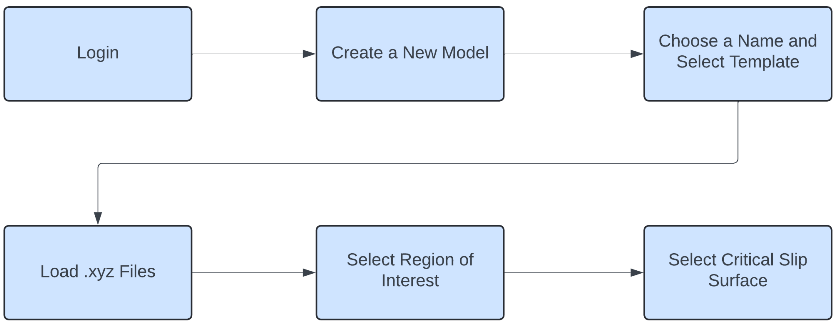

Figure 1. The flowchart of the wizard application.

In the following subsections we will explain in detail each one of the steps of the flowchart in Figure 1. The login step will be skipped, as it is a pretty self-explanatory and common step in programs and applications.

2.1 Home

After the login screen, the user is presented with the home screen, shown in Figure 2. In this window, the user can access previous models that he created or models that were shared with him. There is also a settings button and user information, with notifications about new models. The focus of this work is to present the functionality of the create a new model button, that will take the user to the creation screen, that will be described in the next subsection.

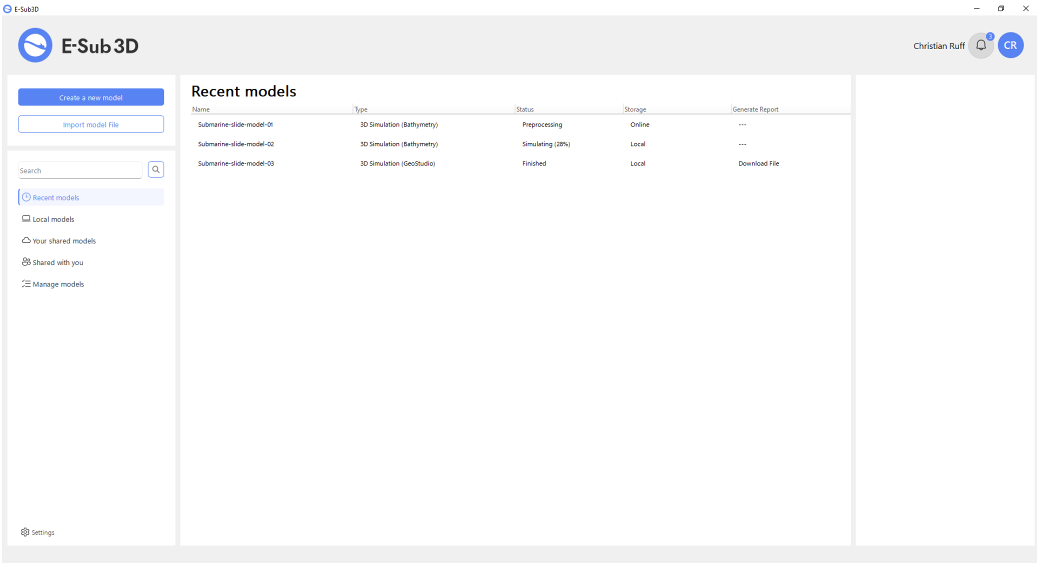

Figure 2. The Home Screen of the application, where the create new a model button is.

2.2 Create a New Model

The Figure 3 displays the screen where the user will choose a name for the new model and select a template from the available types of template. In this work, the focus will be on the 3D bathymetry template, where the user inputs the bathymetry files to select the region of interest and the critical slip surface. After inputting a name and selecting the template, the user can click on the next button to advance with the creation process.

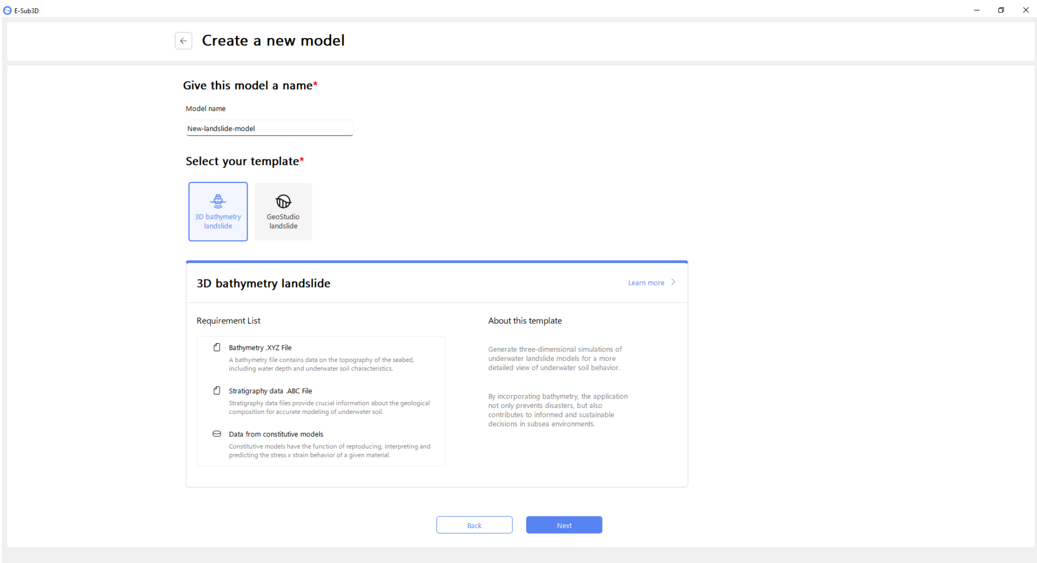

Figure 3. The Create a New Model Screen, where the name and template must be selected.

2.3 Loading Bathymetry Files

This is one the most important steps of the whole process of creating a new submarine landslide model. Here is where the user will load the bathymetry files into the program, as shown in Figure 4. The application can support multiple .xyz files loaded at the same time, representing different layers of the seafloor. Currently, the user can add up to ten bathymetry files, each one defining a single layer. If for some reason one of the files is wrong or if the user wants to change one of the files, he can update a particular file and click the sync files button, to update the visualization of such files. After the files are loaded, the next step starts, which is the selection of the region of interest.

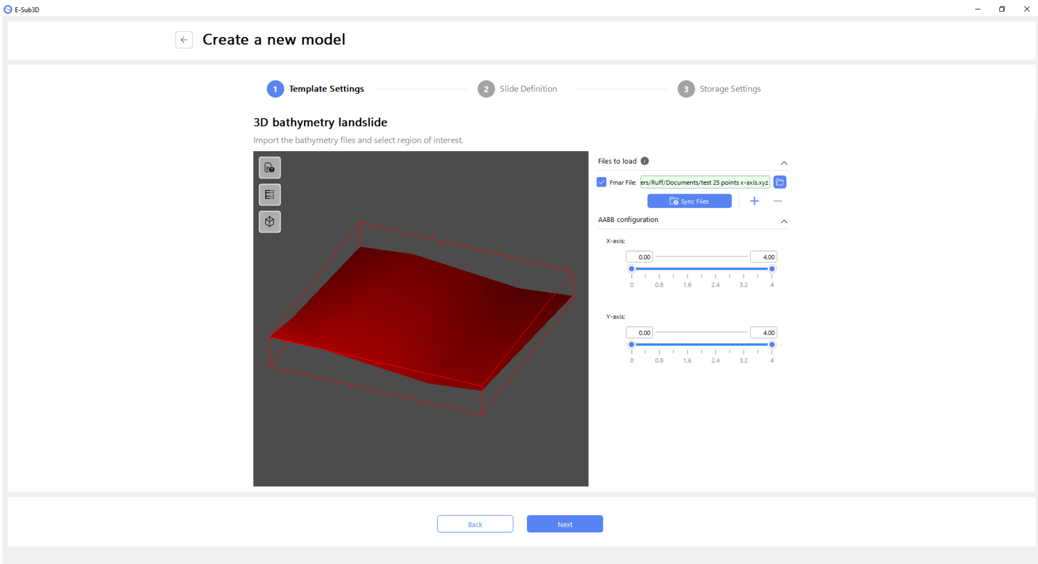

Figure 4. The Load Files Screen, where the user loads the bathymetry files and select the region of interest.

2.4 Region of Interest Selection

Another very important step is the selection of the region of interest. This region will contain the terrain where the simulation will run. Any point outside of this region will be discarded. The region of interest is represented by an axis-aligned bounding box that can be seen in Figure 4 as a red box. This region will always start containing all the points of every file loaded, all the layers. To edit this region, the user can interact with two range sliders, one for the x-axis and the other one for the y-axis. The z-axis, which represent depth is not editable, because it could cause problems like holes in the mesh and lead to inconsistencies. The user can interact with the mesh by rotating it around, zooming in an out, and panning the camera, to ensure that all the terrain's features are included in the region of interest. Once the user completes the editing of the axis-aligned bounding box, he can click next and go to the next step, the critical slip surface selection.

2.5 Critical Slip Surface Selection

The last and most important step is the selection of the critical slip surface. As shown in Figure 5, this screen is where the user must define an area inside the region of interest in which the landslide will occur. To begin this process, the user must select a simple geometry in the menu. After that, set the sliders to change the parameters that define such geometry, as for example, the radius and center of an sphere. By doing so, an intersection zone will start to appear between the geometry and the region of interest. This area is called critical slip surface. The critical slip surface is the dynamic part of the simulation, is the land mass that will slide over time.

Once that is over, there is a simple screen where the user selects if the model will be saved in a local storage or online, but the screen is very simple and it will not be shown in this work.

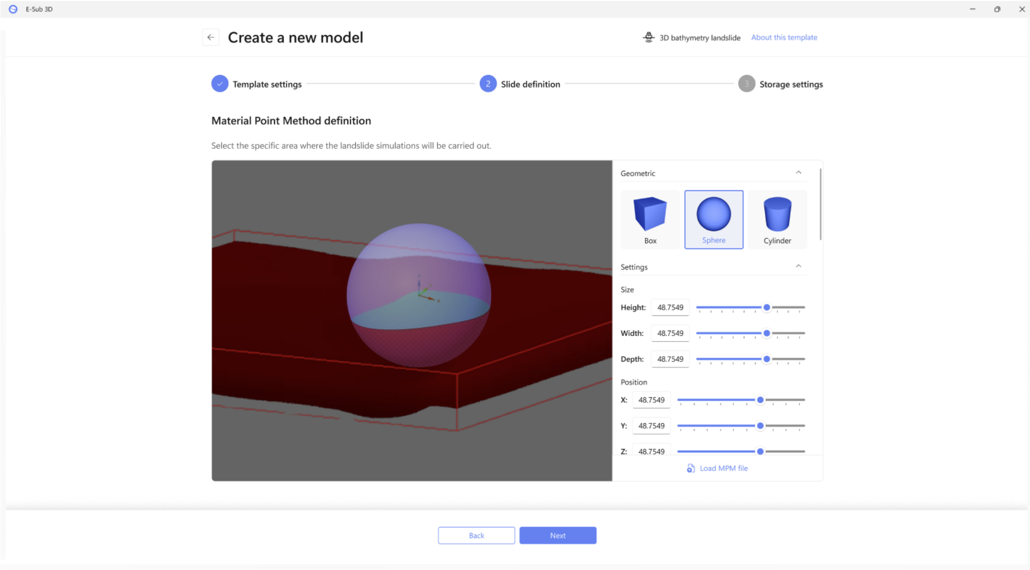

Figure 5. The Critical Slip Surface Selection Screen, where the user interacts with the region of interest to select the critical slip surface.

3 Discussion

A friendly user interface can greatly improve the overall experience of the user. This wizard streamlines numerical parameters by automating and optimizing model choices inherent to the computational method. To be able to select the region of interest and critical slip surface of vast multilayered bathymetry files can significantly improve software usability. This allows the engineer to focus on the physical problem rather than the numerical details. Furthermore, in the landslide simulator, it will be possible to configure a vast range of physical parameters, such as the definition of the sliding mass, the constitutive model and its parameters.

It is possible to create models from other templates besides the bathymetry landslide, like for example the GeoStudio landslide template, shown in Figure 3, which is currently being developed and loads a different type of file with other specifications and screens for the creation of the landslide template.

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