cLiNUs: Computational Landslide Initiation through Numerical Simulations

Version 1.0

User Manual

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Contents

1 Preparation

Note that this application is suitable only for MATLAB R2019a or a later version.

1.1 Installation

Open MATLAB and press the “Install App” icon. The user has to choose the integrated file in the popup window.

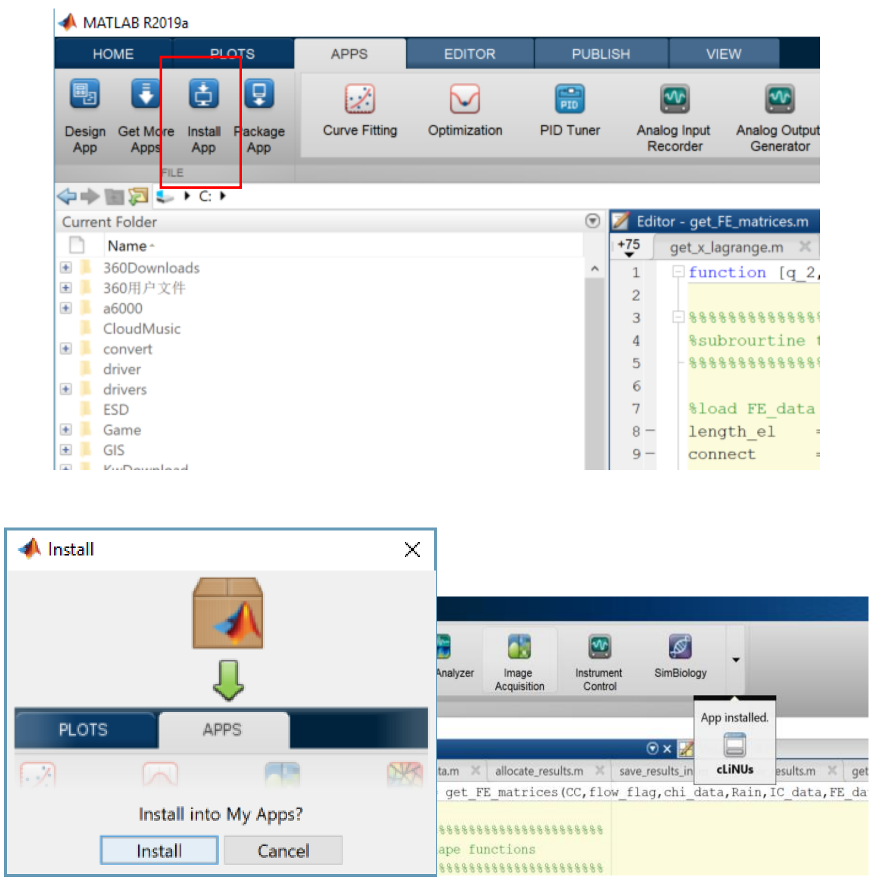


Figure 1-1 App installation

1.2 File management

Create a new fold in your selected drive (e.g., the “C” drive) and name it “convert”. It will be used to collect converted files from .ascii to .raster format. (e.g., “C:\convert”).

2 Introduction of cLiNUs

2.1 FE Settings

The "*FE settings*" interface is designed to facilitate the specification of the initial boundary-value problem and the input of the discretization variables required to use cLiNUs. It provides two options for numerical analyses: Single slope vs. Regional scale. By selecting either option, the corresponding subpanel will be enabled. As shown in Figure 2-1, "Single slope" will be chosen by default. Several parameters are required to initialize the FE setting (i.e. time stepping, nodal discretization, total simulation time). Note that the initial number of time steps here suggested is 5000, but if the results do not converge, the user can increase their number through trial-and-error. Information about the slope geometry only requires the thickness of the slope and its inclination. The discrete knob allows recording nodes of interests throughout the soil column.

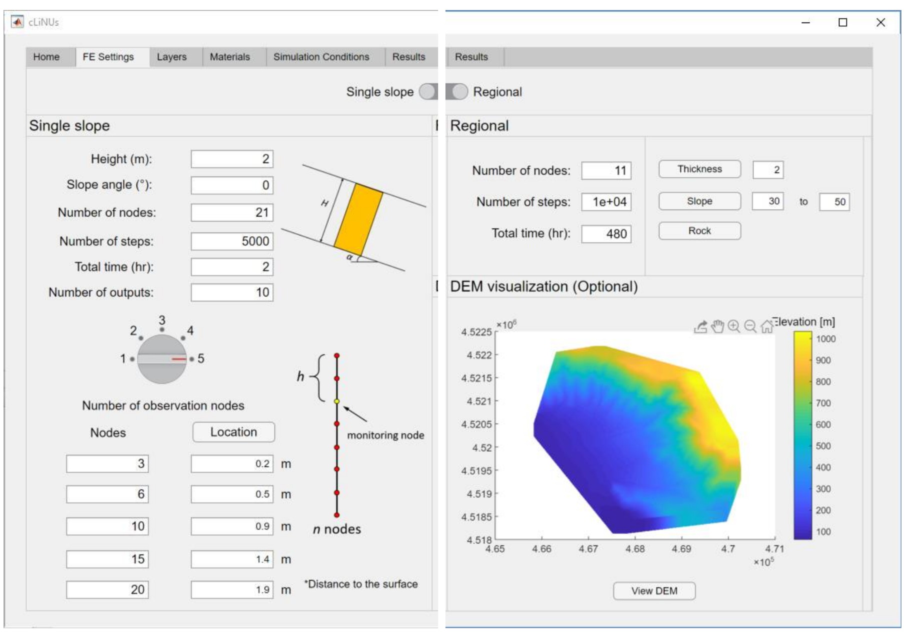
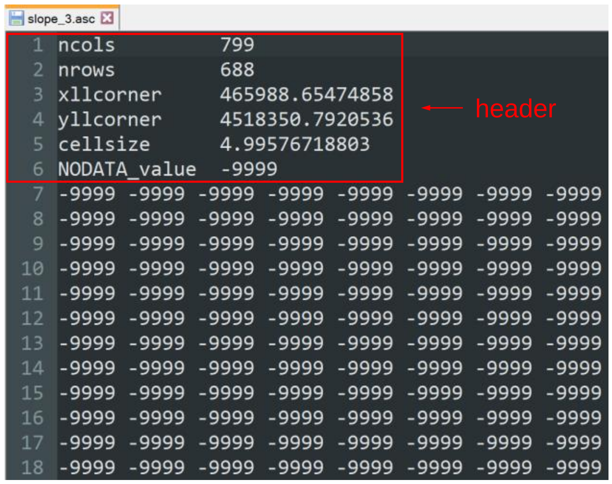


Figure 2-1 View of the *FE Settings* window: the left side shows the settings for single slope analyses, while the right side shows the input interface for regional scale simulations

If the "Regional" option is selected, three geo-referenced maps provided in the form of ASCII files with a specific header are required to input to the program (See Figure 2-1 Right). The header is a georeferenced dataset which contains the size of the map, the coordinates of the corner and the cell size. In Figure 2-2, line1 to line6 illustrate the basic structure for the header. Users are allowed to restrict the computation further by specifying a range of slope angle and thickness.



```
slope_3.asc
1  ncols         799
2  nrows         688
3  xllcorner     465988.65474858
4  yllcorner     4518350.7920536
5  cellsize      4.99576718803
6  NODATA_value  -9999
7  -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999
8  -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999
9  -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999
10 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999
11 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999
12 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999
13 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999
14 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999
15 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999
16 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999
17 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999
18 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999
```


Figure 2-2 Input file header.

2.2 Layers

This part involves the specification of the heterogeneity of a soil layer, as well as the assignation of the soil properties, as shown in Figure 2-3. A cumulative depth weight, α_i (i<=n), is used for assigning the location of the layers. The maximum number of the layer is currently set to five. By turning the knob, the corresponding layer location input will be activated and the corresponding value of α will be required. In Figure 2-3, a slope with four layers is defined and the location of the base of each layer coincides with the product of α and the total thickness. As a result, α for the deepest layer is equal to “1”. If not specific assignation of slope layering is given by the user, the default choice is that of homogenous slope.

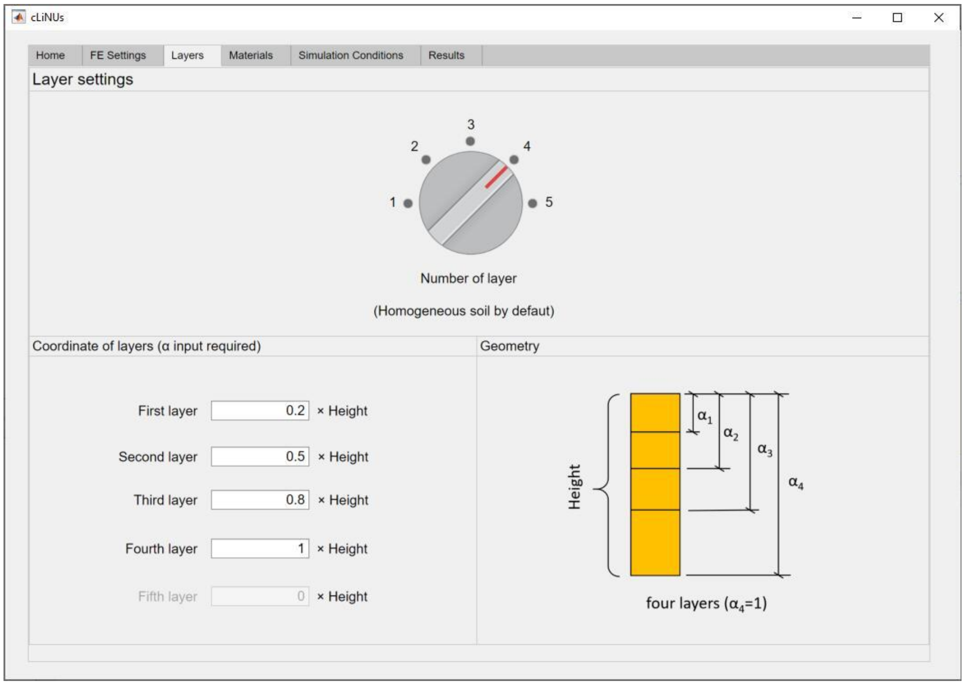


Figure 2-3 *Layer* interface through which the stratigraphy can be defined through the cumulative depth weight (CDW).

2.3 Materials

For convenience, the "*Materials*" interface is organized in two subsections as shown in Figure 2-4 (a). The "Hydraulics" tab provides three models for water retention curve (WRC) and hydraulic conductivity function (HCF), namely Van Genuchten, Gardner and Brooks and Corey models. For each layer, users are required to define the properties completely. The "Root Water Uptake Model" (RWUM) (Prasad, 1988) is inactive by default and will be used only when the "Sink term" switch is on (See 2.6). The "flow rate" switch allows users to calculate the infiltration/runoff rate. A user-defined threshold is required to determine the saturated condition for unsaturated soils. As for the "Mechanical" tab, it mainly used for the stability analysis. The user can choose either Bishop single effective stress (Bishop and Blight, 1963) or Independent stress variables (Fredlund and Morgenstern, 1977) approach to compute the FS (Figure 2-4 (b)). Table 1 shows the required parameter in Mechanical tab.

Figure 2-4 *Materials* interface through which hydraulic and mechanical models can be specified.

Table 1 Mechanical parameter required in cLiNUs

<table>
<tr><td rowspan="4">Stress approach</td><td rowspan="3">Effective stress approach</td><td>$\chi = S_r$</td></tr>
<tr><td>$\chi = \begin{cases} \left(\dfrac{s}{s_e}\right)^{-0.55} & if \;\; s > s_e \\ 1 & if \;\; s \le s_e \end{cases}$</td></tr>
<tr><td>χ = constant</td></tr>
<tr><td>Independent stress variables approach</td><td>Suction elastic modulus, F (Pa)</td></tr>
<tr><td rowspan="2">Elastic modulus</td><td colspan="2">Elastic modulus, E (Pa)</td></tr>
<tr><td colspan="2">Shear modulus, G (Pa)</td></tr>
<tr><td rowspan="3">Strength parameters</td><td colspan="2">Friction angle, φ' (°)</td></tr>
<tr><td colspan="2">Cohesion, c (Pa)</td></tr>
<tr><td colspan="2">Unit weight (N/m^3)</td></tr>
</table>

2.4 Simulation conditions

The *"Simulation conditions"* window interface includes two main components, namely the initial condition settings and the flow boundary conditions (flow BCs), as shown in Figure 2-5. The initial condition is defined as the water head profile along the slope depth at the onset of the simulation. Such profile can be readily assigned in the form of depth-dependent suction conditions. The GUI offers two options for the definition of the flow boundary conditions: flux control and pressure (water head) control, as shown in Table 2. The former requires the assignation of the hydraulic forcing (e.g., rainfall), mathematically represented by a Neumann boundary condition, while the latter requires the prescription of water pressure or water head at one of the boundaries of the domain, mathematically representing a Dirichlet boundary condition.

Table 2 Two options to apply loading

Option	Loading
Flux control	Rainfall, q (m/hr)
Water head control	Water head, h_w (m)

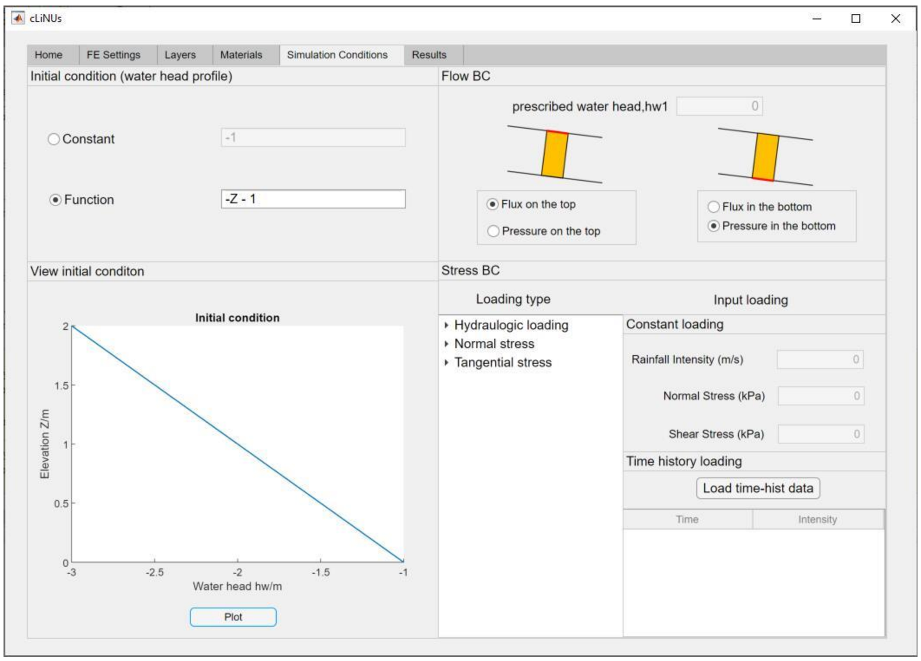


Figure 2-5 View of Boundary condition window. cLiNUs provides several combinations of boundary conditions for various of simulation purpose.

2.5 *Loadings*

The "*Loading*" interface enables the definition of the forcing agents driving the simulation. The loading type is designed to a two-level tree frame. In the first level, users can choose hydrologic loading, normal loading and tangential loading. Within each level, the second level provides two options for processing loading data: (i) by typing constant loading data or (ii) by importing time-history loading data directly from existing files by choosing the "*load time-hist data*" button. A browsing window will appear to help users select the appropriate files easily. Note that the current version of the app only supports .xls files.

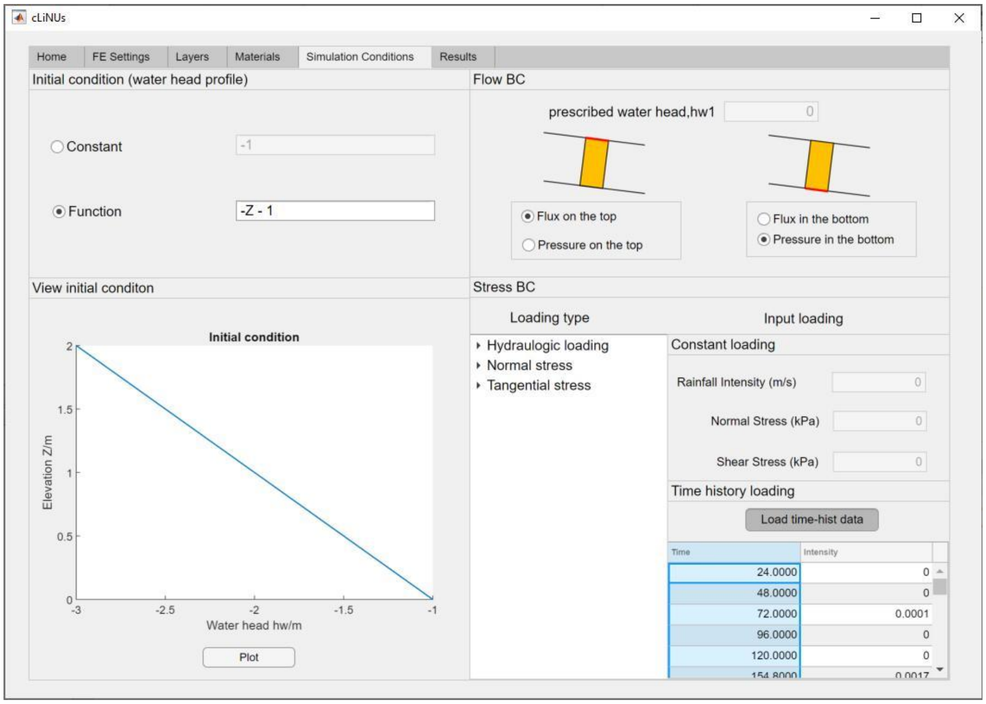


Figure 2-6 View of the *Loading* window

2.6 Results

2.6.1 Single slope

The format of the "Results" interface will adapt to the initial choice done for the type of analysis. For single slope analyses, two functional switches are available: "Coupling effects" and "Sink term".

(i) "Coupling effects"

When the "Coupling effects" switch is on, it allows simulating rigid, swelling or compacting behavior of the unsaturated soil upon wetting. Such option is available only in conjunction with the "Independent variables" approach (to be chosen in the mechanical material settings).

Table 3 soil behavior controlled by suction elastic modulus, *F*

Sign	Soil behavior
$F < 0$	Collapsible soil
$F > 0$	Swelling soil

* when "Coupling effects" is off, it assumes *F* is infinite.

(ii) "Sink term" switch

When the "Sink term" is on, the "Root Water Uptake Model" panel will be active in the *Materials* window.

(iii) Plot option

Once a simulation is completed, the users can plot the results by choosing a plotting category.

Table 4 Plot option in cLiNUs

Items	Variables
Load	Rainfall
Profile variation	Water head
	Degree of saturation
Time history	Infiltration rate
	Runoff rate
	Cumulative infiltration
	Cumulative runoff
Slope stability	Factor of safety

Users are also allowed to check the plotting result by superposing data from existing files (.xls) through the "*Load data*" button, as shown in Figure 2-7 (a). The data source can derive from either experimental data or field test data.

2.6.2 *Regional analysis*

For regional analyses, in order to visualize results, it is necessary to keep the output files consistent with the input maps. Therefore, three steps are needed for the processing stage: converting maps → loading maps → visualizing maps, as shown in Figure 2-7 (b).

Table 5 Detailed introduction for displaying regional results

Function	icon	Description
Calculation	**Click to start**	Run regional simulation
	Save results	Save results as .mat
	Load results	Load existed results as .mat
Convert .ascii to .raster	Abstract header	Abstract header from any geo-referenced map (e.g. slope map, property map and thickness map)
	Transfer to .raster file	The app will automatically save results as .asc file
Load geo-raster	Load DEM	Load DEM map (.asc file)
	Load source area	Load landslide area (polygon)
	Load Failure time	Load Failure time map (.asc file)
	Load Failure depth	Load Failure depth map (.asc file)
	Load Cumu_IR	Load cumulative infiltration (.asc file)
	Load Cumu_Runoff	Load cumulative runoff (.asc file)
Visualization	View map	Display maps
	Clear map	Clear maps

Figure 2-7 Results interface, through which the output of: a) Single slope analyses and b) regional scale analyses can be visualized

3 Examples of simulations with cLiNUs

3.1 Runoff simulation on single slope infiltration

3.1.1 Steady rainfall

Consider a homogeneous soil with thickness L = 50 cm and consisting of loamy sand. Its hydraulic conductivity is modeled by Brooks and Corey's function with K_s = 2cm/h, h_w = -0.226m, θ_s = 0.43, θ_r = 0.08, λ =0.53. The initial condition for the water head h_{w_ini} = 0.8828m. Below are the specific steps for parameter settings:

a. FE_Settings

- Choose "Single slope" switch to enable corresponding window
- Basic parameters can be set as:

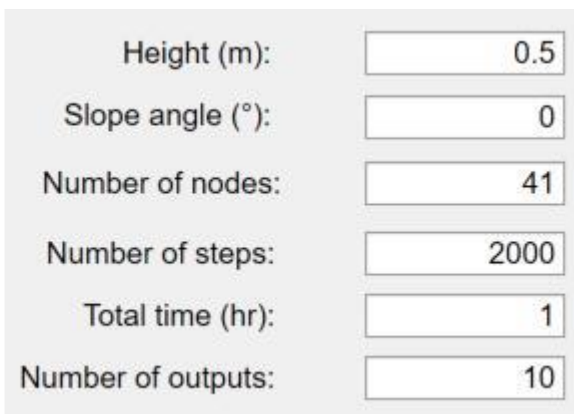


Figure 3-1 FE Settings.

- Choose any observation node as you want.

  Here, two observation nodes located at depth of 0.05m (upper) and 0.3m (middle), respectively are chosen, as shown in Figure 3-2.

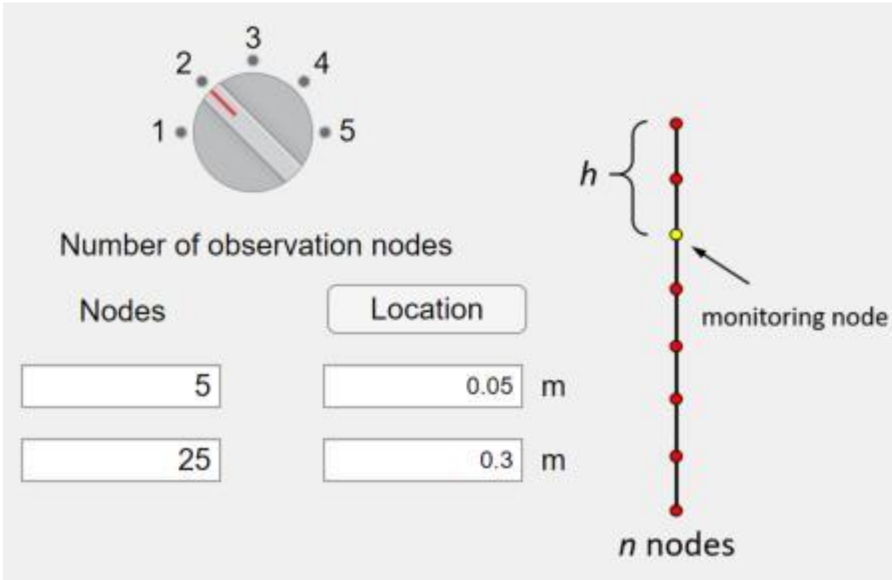


Figure 3-2 Selecting of observation nodes

b. Layer setting

Choose single layer to model a homogeneous slope.

c. Materials

- Activate the “Flow rate” button and set hw2 to be -0.226 m.
- Choose the Brooks and Corey model in the dropdown list of hydraulics models.

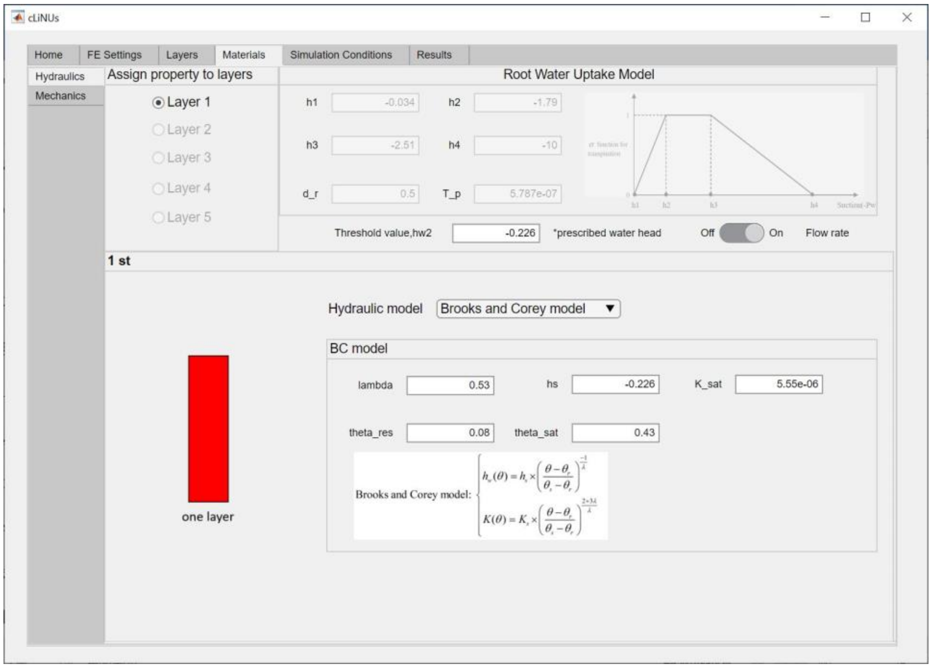


Figure 3-3 Choice of hydraulic model for WRC and HCF.

- Keep default settings for the stress approach and assign the parameters.

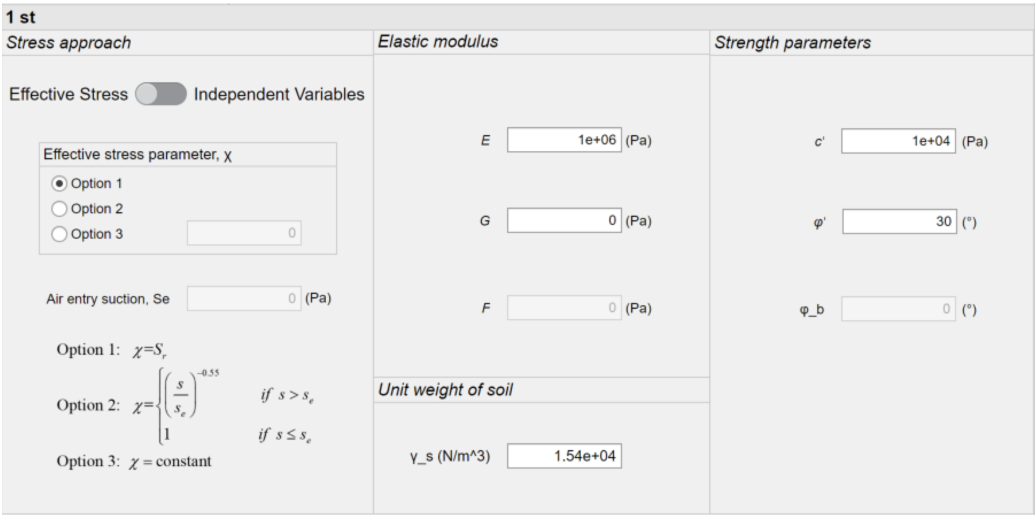


Figure 3-4 Mechanic model choose for slope stability analysis.

d. Boundary conditions

- Set a constant water head equal to -0.8828m
- Keep the remaining settings to their default values

e. Loading

- Set constant rainfall as intensity of 1.11e-5 m/s

f. Results

- Turn on “Flow rate” switch
- Input the threshold value “hw2” as -0.226m. This value controls the saturated condition and will used for infiltration/runoff calculation.
- Press “Click to start” to run the analysis

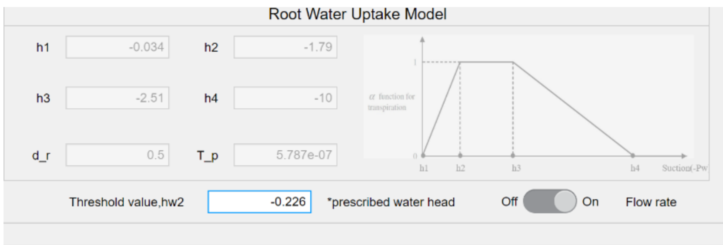


Figure 3-5 Setting runoff calculation condition

- Visualize results

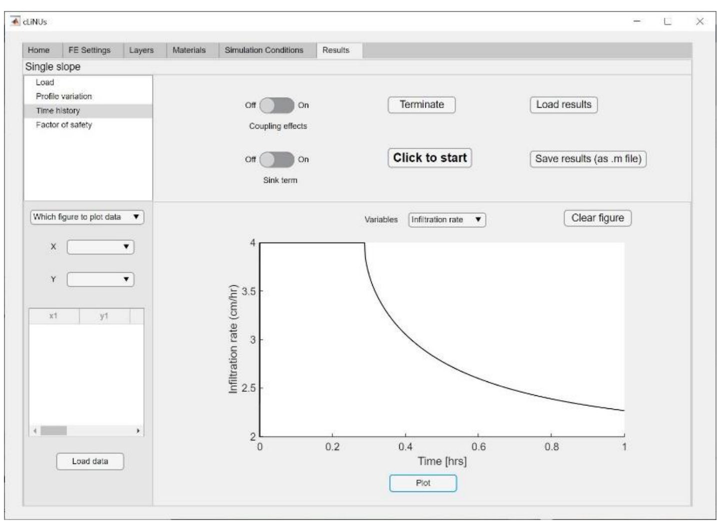


Figure 3-6 Checking results

3.2 Visualize regional landslides susceptibility mapping: loading from results

Given the substantial running time often typical of realistic regional-scale analyses, for simplicity this tutorial shows exclusively how to load existing results and visualize them.

1. Load results

   Press the “Load results” button to choose and load an existing .mat file. After loading it, you will see a popup window.

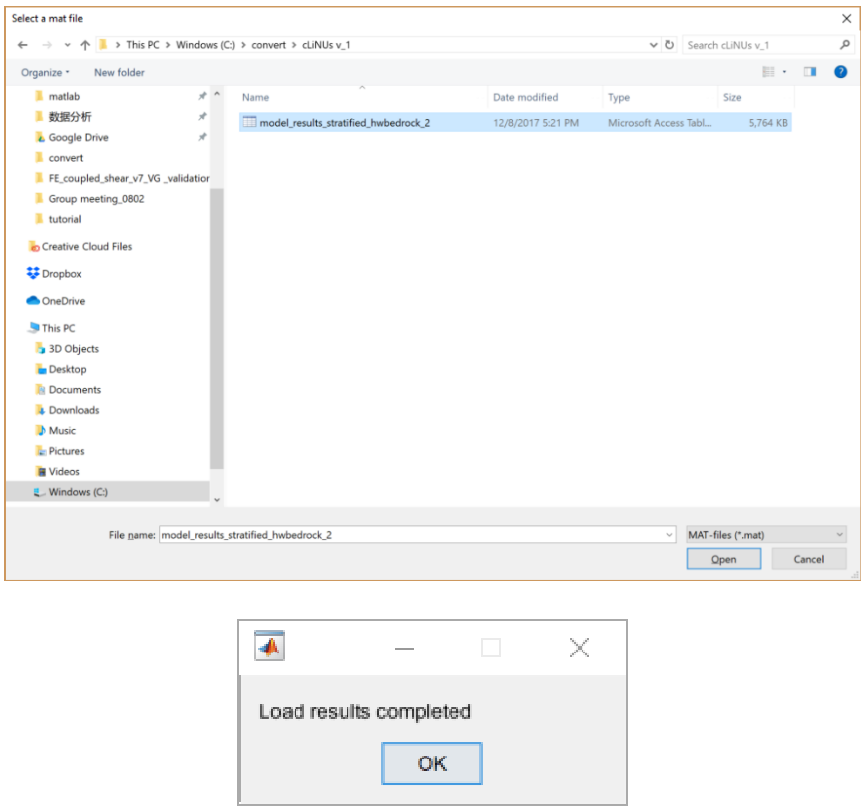


Figure 3-7 Loading results and popup window

2. Convert the results to the geo-referenced .raster format.

   1) Press “Abstract header” and choose the header from any three input maps.

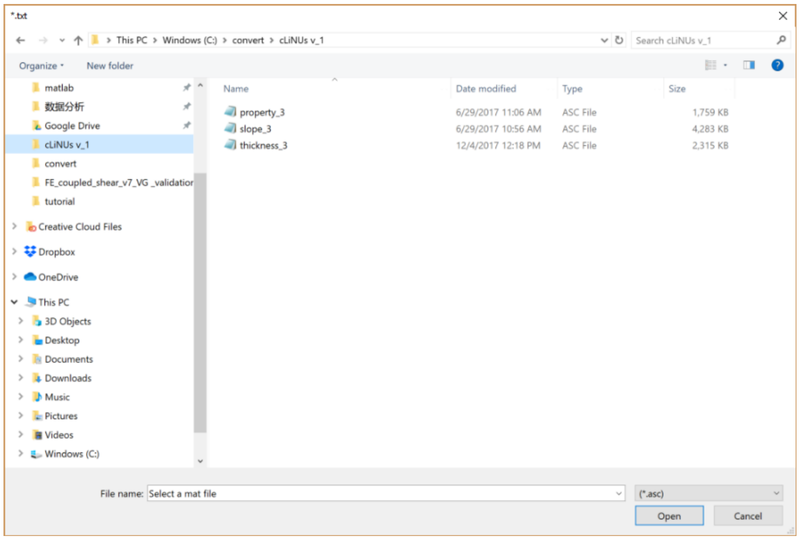


Figure 3-8 Select header

2) Choose variable from the dropdown list:

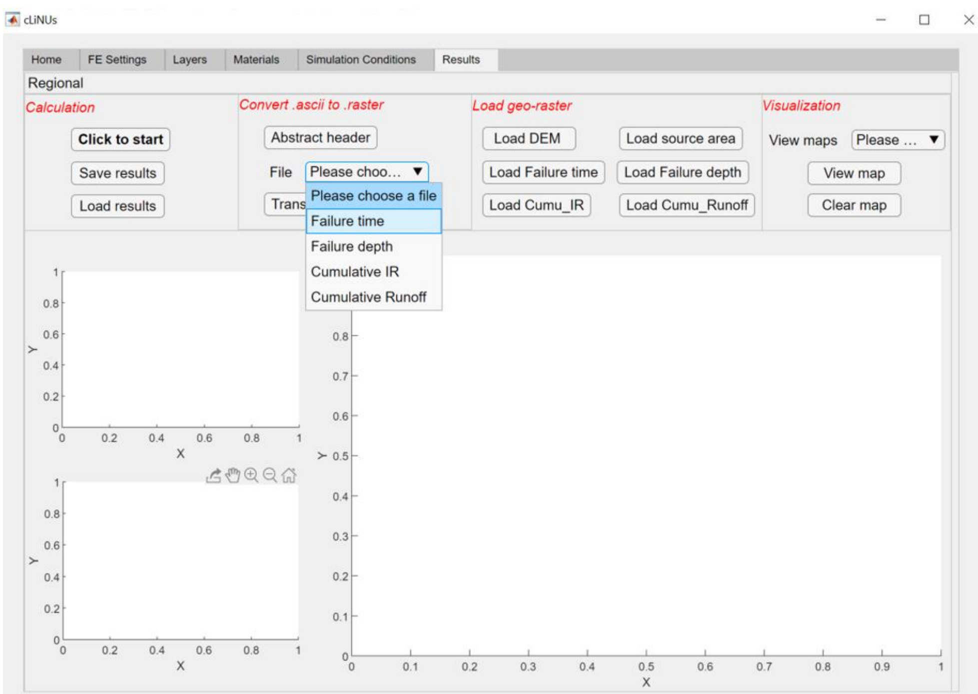


Figure 3-9 Select variable

3) Press the “Transfer to .raster” button to see a new popup window:

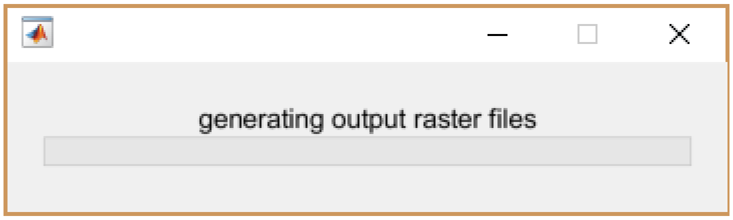


Figure 3-10 Generate raster file

4) Overlap maps by loading the .raster files

   e.g. overlap DEM with Failure time

5) View maps

   After selecting the map, the users need to specify its corresponding variable by a dropdown list.

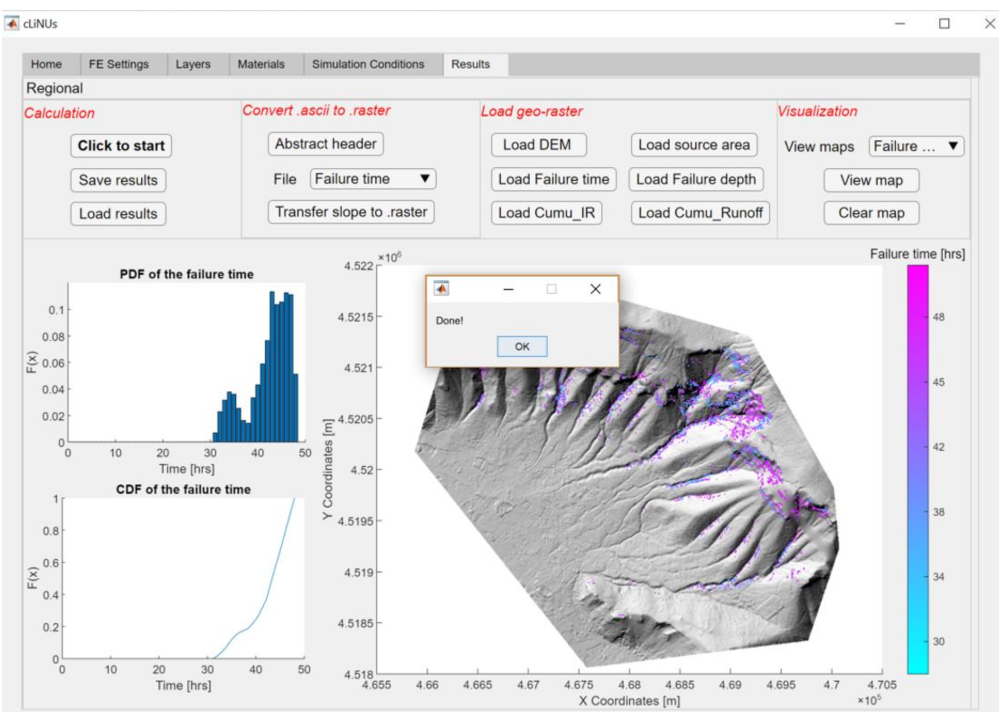


Figure 3-11 View results

4 Troubleshooting

1. The app has “memory”, which means when users want to repeat the simulation, you don’t need to input again all the parameters, except those in the “**Loading**” tab.

```
Undefined function or variable 'i_q'.

Error in get_LD_data (line 73)
    LD_data.qr           = i_q(1);

Error in App_v14/ClicktostartButtonPushed2 (line 2667)
        LD_data = get_LD_data(app.time_final,app.Loading_Index,app.q_r,app.q_py,app.q_px, app.RI_Table2.Data);

Error using matlab.ui.control.internal.controller.ComponentController/executeUserCallback (line 335)
Error while evaluating Button PrivateButtonPushedFcn.
```

This mean that the loading input (i.e., rainfall) has not been specified. The user has to go back to the “loading panel” and provide its intensity to resolve the problem.

5 Appendix

5.1 Water root uptake model

The approach proposed by Prasad (1988) to simulate root water extraction has been implemented, which involves a linear variation of the extraction rate with depth. This approach requires the incorporation of a sink term expressed as:

$$S_{\text{sink}} = \frac{2\beta T_p}{d_r}\left(1 + \frac{z}{d_r}\right)$$

The relation above assumes a linear decrease of the root extraction term with depth until the maximum rood depth, d_r at which the water uptake becomes zero. The term T_p indicates the total potential transpiration rate, z is the current depth and β is a multiplicative coefficient dependent on suction as shown in Fig. 5-1.

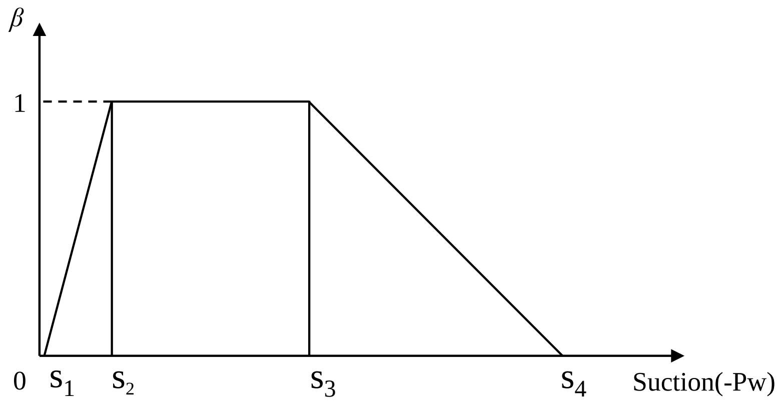


Fig. 5-1 Linear variation of β which is suction dependent.

Where S_1 and S_4 called the anaerobiosis point and the permanent wilting point, respectively. The Root water uptake is assumed to be nil at pore water suctions (i.e. tensile pore water pressures) higher than S_4, and below S_1. The latter equates to water logged conditions when roots are unable to function. Root water extraction is assumed to be at its maximum and constant between points S_2 and S_3. A linear variation of a with pore water suction is assumed between S_1 and S_2 and between S_3 and S_4.

6 Reference

Bishop, A. W., & Blight, G. E. (1963). Some aspects of effective stress in saturated and partly saturated soils. Geotechnique, 13(3), 177-197.

Fredlund, D. G., & Morgenstern, N. R. (1977). Stress state variables for unsaturated soils. Journal of Geotechnical and Geoenvironmental Engineering, 103(ASCE 12919).

Prasad, R., 1988. A Linear Root Water-Uptake Model. Journal of Hydrology. 99, 297-306.