HYRCAN: A Comprehensive Limit Equilibrium Software Package for 2D Slope Stability Analysis

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Abstract

This paper presents the application software *HYRCAN*, which evaluates the factor of safety of circular failure surface in soil or rock slopes. *HYRCAN* offers a stand-alone windows system that is very simple to use, yet complex models can be created and analyzed quickly and easily. The graphical user interface enables quick generation of advanced models, and the enhanced output facilities provide a detailed presentation of computational results. The analysis procedures are fully automated and based on robust numerical procedures. Embedded scripting languages in *HYRCAN* enable the user to interact with and manipulate the models. This paper addresses the capabilities provided by pre- and post-processors for slope stability analysis and suggests enhancements and new features likely to be developed in the near future.

HYRCAN: A Comprehensive Limit Equilibrium Software Package for 2D Slope Stability Analysis

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Abstract

This paper presents the application software *HYRCAN* , which evaluates the factor of safety of circular failure surface in soil or rock slopes. *HYRCAN* offers a stand-alone windows system that is very simple to use, yet complex models can be created and analyzed quickly and easily. The graphical user interface enables quick generation of advanced models, and the enhanced output facilities provide a detailed presentation of computational results. The analysis procedures are fully automated and based on robust numerical procedures. Embedded scripting languages in*HYRCAN* enable the user to interact with and manipulate the models. This paper addresses the capabilities provided by pre- and post-processors for slope stability analysis and suggests enhancements and new features likely to be developed in the near future.

Keywords

Slope stability, limit equilibrium method, circular failure surface, scriptable, Python, JavaScript

Introduction and Motivation

Slope stability is of significant importance for sustainable development in mining, civil engineering, and urban planning. Not only can reliable slope design in mining and civil engineering projects improve safety, but it can also avoid unexpected construction cost overruns resulting from slope failure. Limit equilibrium

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method (LEM) has been widely used for slope stability analysis in engineering practice. In LEM, the factor of safety (FOS) for a large number of potential slip surfaces is calculated, and the slip surface with the minimum FOS is defined as the critical slip surface, along which sliding is most likely to occur.

A number of commercial slope stability software is presently available on the market, including *Slide2* [1], *SVSlope* [2],*Slope/W* [3], *XSTABL* [4], and *UTEXAS4* [5]. They typically meet the requirements of an out-of-the box solution for the end user, but most often at the cost of black box procedures. However, from an academic perspective, these software packages can be expensive and the back-end structure of the algorithms often is not completely understood or available for users. Consequently, there has been growing interest in the scientific community to develop both open-source and free access slope stability programs to overcome these limitations, such as *pyBIMstab* [6], *r.slope.stability* [7],*pyslope* [8], and *LEMSlope* [9]. However, the open-source programs most often do not provide a fully integrated and efficient graphical user interface (GUI) and further post-processing for data analysis.

To address these issues, the author has introduced *HYRCAN* , a comprehensive limit equilibrium software for slope stability analysis, which is a freely accessible program. *HYRCAN* is developed for analyzing two-dimensional (2D) soil or rock slopes by LEMs. The software employs the object-oriented programming (OOP) approach for both the GUI and the analysis solution modules. The pre- and post-processors, with a friendly GUI environment, allow users to construct complex geometries, apply loads and supports, perform analyses, and display solutions with ease. These characteristics give *HYRCAN* a high potential to be used for educational and research purposes.

Software description

HYRCAN is a command-driven program that can be run either interactively or from an ASCII data file. *HYRCAN* comes with a GUI that offers most of the common features a user might already know from other applications. The developer of *HYRCAN* used “Qt” GUI components such as: Checkbox, Radio Button, Numeric Up/Down, Data Grid View, and Combo box in a suitable manner to achieve easy and user-friendly functionality. For example, when more than one choice is possible, the use of Checkbox is implemented, whereas Radio Buttons are used when a single choice is to be selected. Numeric Up/Down Arrows are used for easily scrolling through predefined numerical values, such as integers when defining number of columns and number of beams. Data Grid Views are used when tabulated information is required, such as when inputting story elevations or nodal weights.

Most functions of *HYRCAN* can be accessed from its menu and toolbar. *HYRCAN* commands can be executed in three ways: (1) selecting a corresponding tool icon on one of the toolbars; (2) choosing a menu item from one of the pull-down menus; or (3) typing the command at the command line. Some actions might require further input after launching.

Figure 1 illustrates various parts of the *HYRCAN* graphical environment. The application will be launched in a standard dialog window containing all the managing tools typical for a Windows environment (minimizing, maximizing, and closing the program window). The program window consists of a menu and toolbars, legend window, command line, and graphics window that gives a visual of the executed tasks.

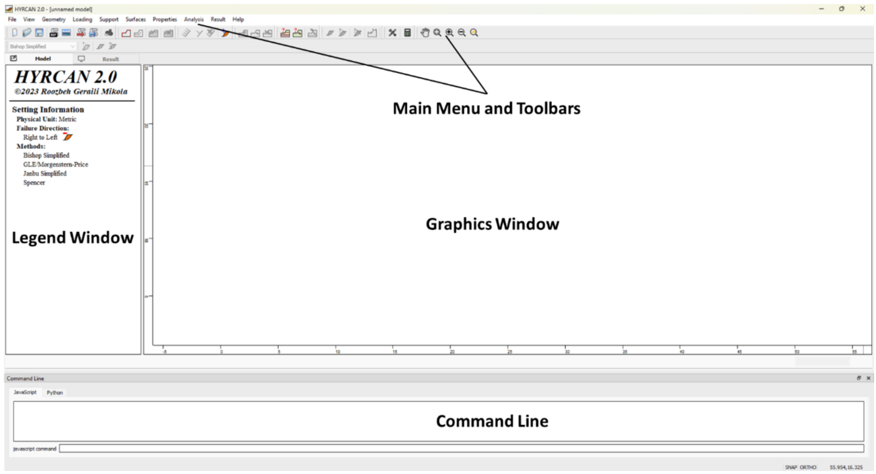

Figure 1 - *HYRCAN* main graphical user interface.

Software architecture and functionality

HYRCAN is developed as a stand-alone and free program, which is fully written in C++ with the cross-platform framework Qt. The overall structure of *HYRCAN* is based on an object-oriented modular approach. *HYRCAN* contains four main modules, as shown in Figure 2: (1) pre-processing, (2) solver, (3) post-processing, and (4) embedded scripting. Each module is described in detail in the following subsections.

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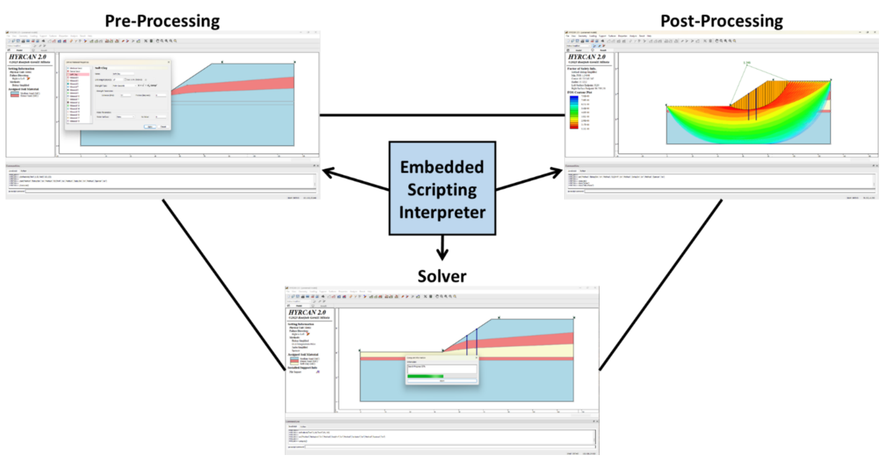

Figure 2- Working flow of *HYRCAN* .

Pre-processing

HYRCAN provides powerful CAD-based modeling features for defining the model geometry. Geometries can be defined by (1) drawing with the mouse; (2) entering coordinates on a prompt line; and (3) executing drawing commands via scripting languages. The prompt line can be used for entering coordinates as well as other command prompts available in the *HYRCAN* program. A snapping feature is implemented to greatly simplify the drawing process. The main features of the pre-processing GUI are listed below:

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- Boundaries are added using the External Boundary, Material Boundary, and Add Water Table options.
- A maximum of 20 material types can be defined in the Define Material Properties dialog.
- Currently, three types of strength models (Mohr-Coulomb, Hoek-Brown, and SHANSEP) are available for modeling shear strength of the various materials of the model.
- The material properties can be assigned to the model's regions using the Assign Properties option in the toolbar or the Properties menu, or via command line.
- The Slope Limits can be defined at any time.
- Specific circular slip surface can be defined in the model for the analysis.
- Groundwater may be specified in two ways:

A constant of Bishop's pore water pressure, Ru.

A piezometric line where the pore water pressures are computed as the vertical distance between the piezometric line and point of interest multiplied by the unit weight of water. If a water table is drawn above the external boundary, *HYRCAN* will automatically create a region of ponded water below the water table and above the external boundary.

- Various types of external loading (such as distributed loads, line loads, and seismic loads) can be applied to a model using the options in the Loading menu.
- Various types of slope reinforcement can be modeled in *HYRCAN* , including (a) end-anchored support, (b) grouted tiebacks, (c) soil nails, (d) geotextiles, and (e) piles.
- Boundaries and supports can be imported into *HYRCAN* from a DXF file (AutoCAD Drawing Exchange Format).
- The Export Image option allows users to save the current view directly to PNG (*.png) file format.
- The default display language can be changed in the Project Setting dialog. The user interface of *HYRCAN* is available in English, Portuguese, Simplified Chinese, Italian, Turkish, Russian, Polish, and Spanish.

Solver

The search for the critical surface requires the generation of many potential circular failure surfaces. The surface with the lowest FOS may then be pronounced as the most critical surface. The number of surfaces examined and the searching area (i.e., slip surface's entry and exit area) are specified by the user. *HYRCAN* employs Slope/W's unique method of surface generation [3] to examine and analyze an unlimited number of surfaces within user-defined regions of the slope.*HYRCAN* analyzes the stability of slip surfaces using vertical slice limit equilibrium methods. The following vertical slice limit equilibrium analysis methods are available in the program:

- Bishop Simplified
- Janbu Simplified
- Spencer
- General Limit Equilibrium (GLE)/Morgenstern-Price

Any or all of these methods can be selected for a given *HYRCAN*analysis. When Solver is run, all of the selected analysis methods will be simultaneously run on the model, and results for all methods will be available for viewing in the post-processing module.

Post-processing

The*HYRCAN*post-processor has a relatively advanced data visualization and interpretation package. Powerful visualization and data management together with mouse navigations allow the user to quickly home in on regions of most interest. Modeling results can be visualized using the graphing tools provided. The post-processor GUI is based on the same graphical display window as that used in the pre-processor. Therefore, much of the functionalities, such as zoom functions and customizable display options, are similar to those of the pre-processor. Additionally, the post-processor incorporates the following:

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- View global minimum slip surface.
- View any or all surfaces generated by search.
- Detailed analysis results can be plotted for individual slip surfaces with the minimum FOS.

Embedded Scripting Languages

While most common operations can be executed through the use of commands, scripting is a vital aspect of the program, allowing users to perform problem-specific operations. *HYRCAN* provides scripting capabilities via both JavaScript and Python.

JavaScript is a scripting language embedded within *HYRCAN* that allows users to interact with and manipulate models, defining new variables and functions as needed. These functions may be used to extend, add to, or control the program. For example, JavaScript can be used to plot or print new variables, parameterize models, control model runs, create/calculate new model outputs, monitor results, and post-process model runs.

In addition to JavaScript, the Python scripting language is also embedded in *HYRCAN* . Python is an open-source, object-oriented, interpreted, and interactive high-level programming language. Like JavaScript, the Python scripting language is interpreted at runtime by embedded interpreter. Scripts can be written in ASCII files and loaded into the program via user interface (e.g., menu or toolbars) or command line.

Illustrative examples

We present three examples demonstrating the capabilities of*HYRCAN* . The results are compared against the results obtained using commercial software. One of the key aspects of these examples is to assess the efficiency of the proposed program in solving the problems. All calculations were performed on a personal computer with an Intel Core i3-8100 CPU 3.60 GHz processor.

Example 1

This example concerns three materials with different strength types presented together in a slope. The slope dimensions and outcome of the analysis are provided in Figure 3, where soil represents a Mohr-Coulomb material with different strength parameters. The parameters for the soil layers are listed together in Table 1. In this example, a horizontal seismic acceleration of 0.15 g is applied to the slope. The calculated minimum FOS by HYRCAN using several methods are compared with commercial software packages such as Slide2 [1] and SVSLOPE [10], as shown in Table 2. The FOS provided by HYRCAN are in good agreement with other commercial programs (Table 2).

Table 1 - Material Properties of the Non-Homogenous Model

Material	c **(kN/m^2)**	φ **(degrees)**	γ **(kN/m^3)**
Soil 1	0.0	38.0	19.5
Soil 2	5.3	23.0	19.5
Soil 3	7.2	20.0	19.5

Table 2 - Comparison of Minimum FOS for Non-Homogeneous Model

Method	Slide2	SVSLOPE	HYRCAN
Bishop Simplified	1.015	1.104	1.013
Janbu Simplified	0.897	0.897	0.897
Spencer	0.991	0.991	0.990

Method	Slide2	SVSLOPE	HYRCAN
GLE/Morgenstern-Price	0.989	0.991	0.988

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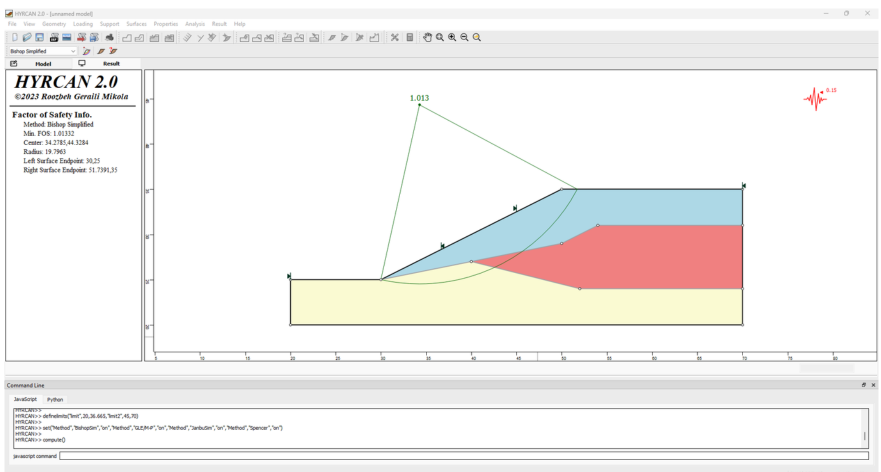
(a)



(b)

Figure 3 - Example 1: (a) Geometry of the non-homogeneous with seismic load model. (b) Results using the Bishop Simplified method for the non-homogeneous model.

Example 2

This tutorial demonstrates the modeling of a geosynthetic reinforced retaining wall in HYRCAN. A 2D retaining wall model (Figure 4) was developed using HYRCAN and Slide2 software. The properties of the soil layers are listed in Table 3. Fourteen layers of geosynthetic reinforcements were placed with a vertical spacing of 0.6 m. In this example, all FOS calculated by HYRCAN and Slide2 are in good agreement with the acceptable range.

Table 3 - Material Properties of the Non-Homogenous Model

Material	γ (kN/m^3)	c (kN/m^2)	φ (degrees)
Backfill	21.7	1.0	33.0
Wall	20.4	0.0	41.0
Glacial till	20	2.0	54.0

Table 4 - Comparison of Minimum FOS

Method	Slide2	HYRCAN
Bishop Simplified	1.493	1.459

Method	Slide2	HYRCAN
GLE/Morgenstern-Price	1.495	1.459
Janbu Simplified	1.328	1.323
Spencer	1.494	1.458

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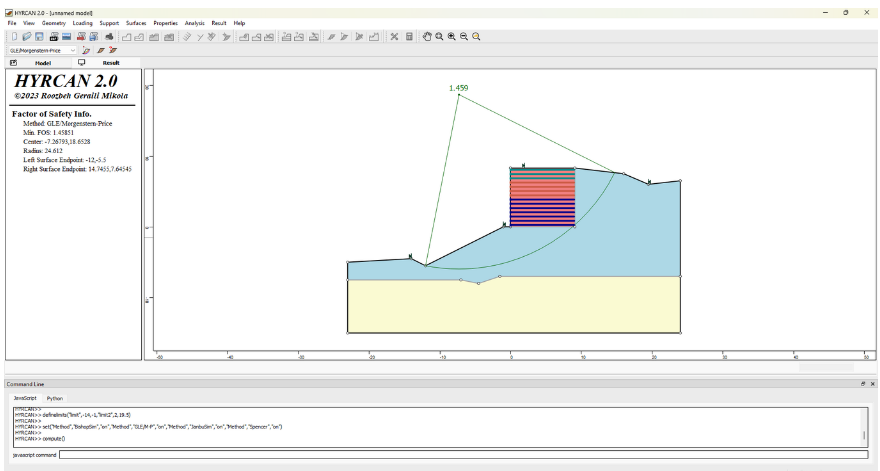
(a)



(b)

Figure 4 - Example 2: (a) Geometry of the non-homogeneous with seismic load model. (b) Results using the GLE/Morgenstern-Price method for the geosynthetic reinforced retaining wall model.

Example 3

This example demonstrates how to use Python in HYRCAN. The script in Listing 1 illustrates a slope analysis that can be performed with HYRCAN. Figure 5 shows the outcome of this analysis. In this example, the property (i.e., cohesion) of the clay layer was modified repeatedly, and calculated FOS is stored in the array list and later exported into an Excel spreadsheet, as shown in Figure 5.

Listing 1- Script used to create example 3 model.

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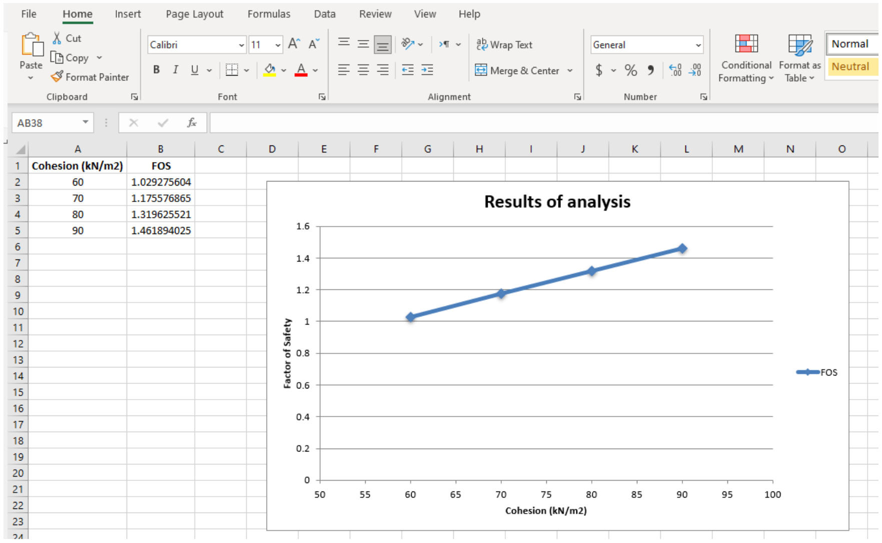

Figure 5 - Exported Excel file that summarizes cohesion versus FOS values.

Impact

HYRCAN represents an excellent option for researchers and practicing geotechnical engineers to analyze and simulate complex 2D slope stability analyses. Early on,*HYRCAN* was used by researchers, but it has now grown to a large international user base. In 2022, *HYRCAN* was downloaded more than 4,000 times from its website, http://www.geowizard.org.

The *HYRCAN* user interface and documentations are being translated into multiple languages (such as Portuguese, Simplified Chinese, Italian, Turkish, Russian, Polish, and Spanish) by a worldwide volunteer community. *HYRCAN* has a user-friendly graphical interface and high computational efficiency and is being used in graduate-level courses at various universities around the world. *HYRCAN* is for new users approaching the world of slope stability analysis for the first time, as well as for experienced users who intend to use it for advanced analysis of complex 2D models. The author anticipates that the popularity of *HYRCAN* will grow over time, owing in part to its powerful built-in tools.

Conclusions

The author presents *HYRCAN,* a free 2D slope stability program for evaluating FOS of circular failure surfaces in soil or rock slopes.*HYRCAN* is simple to use, yet complex models can be created and analyzed quickly and easily. External loading, groundwater, and support can all be modeled in a variety of ways. *HYRCAN* analyzes the stability of slip surfaces using vertical slice limit equilibrium methods. A combination of the GUI, variety of built-in tools, embedded scripting languages, and other relevant features distinguish*HYRCAN* from other existing, freely available slope stability software packages. The author of this paper will continue improving the program by incorporating additional functionality, specifically, implementing the capability of the search for the non-circular critical slip surface with the overall minimum FOS for a given slope.

Declaration of competing interest

The author declare that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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