



Rockfall Dynamics with RAMMS::Rockfall

RAMMS AG

June, 2026

Marc Christen & Perry Bartelt



Title picture: Rockfall impact at Chant Sura, Photo: SLF

Manuscript update
June 2026

Table of Contents

1	Introduction	9
1.1	Motivation	9
1.2	RAMMS.....	10
1.3	Learning by doing	11
2	Installation and Setup	13
2.1	System Requirements.....	13
2.2	Installation	13
2.3	First Start and License Registration	15
3	The RAMMS::Rockfall GUI.....	17
3.1	Starting the Graphical Interface	17
3.2	Project Creation / Opening Input and Output Files	19
3.2.1	Project Creation	20
3.2.2	Understanding the Create Project Wizard/Window	21
3.2.3	DEM Files *.asc and *.tif	21
4	Theory.....	24
4.1	Overview	24
4.1.1	Modelling Approach	24
4.1.2	Rock-Ground Interaction and Motion Modes.....	25
4.1.3	Rock Shape and Geological Control	25
4.1.4	Rock Fragmentation Considerations	26
4.1.5	Rock Rotation and Contact Mechanics	27
4.1.6	Modelling Assumptions and Known Limitations	27
4.2	Modeling Rock Shape	28
4.3	Equation of Motion and Free Flight.....	30
4.4	Free Flight Motion with Gravity and Gyroscopic Forces	31
4.5	Terrain Interaction Phases	32

4.6	Energy dissipation due to rock-ground scarring	33
4.6.1	Drag Forces	33
4.6.2	Drag Torques.....	33
4.6.3	Maximum penetration depth	34
4.7	Hard Contact and Slippage.....	35
4.7.1	Contact forces.....	35
4.7.2	Friction forces	36
4.7.3	Impulsive forces (Rebound)	37
4.7.4	Contact Friction.....	38
4.7.5	Coulomb Friction and Slippage	39
4.8	Terrain/Soil Material	41
4.8.1	Soil Strength <i>ME</i>	46
4.8.2	Drag Coefficient <i>Cd</i>	49
4.8.3	Terrain conditions vs. selected terrain category vs. rock size	50
4.8.4	Calibrating the ground parameters.....	50
4.9	Forest/Vegetation.....	53
4.9.1	Energy Dissipation, Tree Contact and Destruction	54
4.9.2	Lateral Hits and Scratches	55
4.10	Terrain Model.....	56
5	Setting-Up a Simulation.....	58
5.1	Getting Started	58
5.1.1	Topographic data - Digital Elevation Model (DEM)	58
5.1.2	Project and Scenarios.....	61
5.1.3	Preferences	62
5.1.1	Additional Preferences	64
5.2	Creating a new project.....	68
5.3	Working with the interface	70
5.3.1	Moving, resizing, rotating, viewing	70
5.3.2	Colorbar	71
5.3.3	Changing maps and remote sensing imagery.....	72

5.3.4	Hillshade visualization	73
5.3.5	Show Slope Angles or Contour Lines	74
5.3.6	How to save input files and program settings	75
5.3.7	Activity-Log	77
5.3.8	About RAMMS	79
5.4	Shapefiles	80
5.4.1	Drawing Shapefiles	80
5.4.2	Import Shapefiles	81
5.4.3	Calculation Domain	81
5.5	Assign Release Zones.....	82
5.5.1	Release Point.....	82
5.5.2	Release Line	83
5.5.3	Release Area.....	84
5.5.4	Removing Release Zones	84
5.6	Assign Ground Categories	88
5.6.1	Creating Custom Soil Types.....	91
5.7	Forested area	92
5.7.1	Creating Forest Shapefiles	92
5.7.2	Forest Parameters.....	93
5.7.3	Forest Visualization.....	94
5.7.4	An Example of Using Forests	94
5.8	Rock builder	96
5.8.1	Using the rock builder.....	97
5.8.2	Convex hull (point cloud) rigid obstacles	99
5.8.3	Creating Point Cloud Objects Outside of RAMMS	100
5.8.4	Importing External Convex Hull Objects into RAMMS	101
5.9	Barrier objects (nets)	102
5.9.1	Energy Absorption Capacity.....	103
5.9.2	Create new net object: Step-by-step.....	104
5.10	Rockfall Dams, Rockfall Sheds	106
5.10.1	Defining Dam Location and Geometry.....	108

5.10.2	Rockfall Sheds	115
5.10.3	Format of point-cloud-object (Dam or Shed)	117
5.10.4	Structural Impact Parameters for Rocks and Sheds	117
6	Simulation Setup and Execution.....	122
6.1	Seven Tabs	122
6.1.1	General Tab	122
6.1.2	Terrain Tab	125
6.1.3	Forest Tab	129
6.1.4	Dam/Net Tab	131
6.1.5	Rock Tab	134
6.1.6	Release Tab	138
6.1.7	Stop Tab	143
6.2	Selecting Representative Simulation Scenarios	145
6.2.1	Why Multiple Scenarios Are Needed	146
6.2.2	Selecting Representative Block Volume Classes.....	147
6.2.3	Selecting Representative Rock Shapes.....	148
6.2.4	Selecting Release Configurations	149
6.2.5	Combining and Documenting Scenarios	150
6.2.6	Recommended Workflow for Scenario Preparation	151
6.2.7	Practical Recommendations.....	152
6.2.8	Scenario Files and Storage Optimization	152
6.3	Executing the Simulation and Generated Outputs	154
6.3.1	Scenario Overwrite and Naming	154
6.3.2	Random Orientations and Reproducibility	155
6.3.3	Scenario Preparation	156
6.3.4	Simulation Execution.....	156
6.3.5	Scenario Logfile.....	157
6.3.6	Generated Output Files.....	159
6.3.7	Recommended Execution Workflow	160
6.3.8	Notes on Result Interpretation	160
7	Results	162

7.1	Statistics Mode	162
7.1.1	Cell-Based Data Storage	163
7.1.2	Descriptive Statistics	164
7.1.3	Quantile Calculation Method	165
7.1.4	Histogram and Probability Density Function (PDF)	165
7.1.5	CDF and EDF	166
7.1.6	Boxplot Representation	167
7.1.7	Implementation Refinements (since Version 2.0)	168
7.2	Working in Statistic Mode.....	169
7.2.1	Opening a Rockfall Scenario	169
7.2.2	Opening Multiple Scenarios (Filter/Multi)	170
7.2.3	Default Result After Opening.....	171
7.2.4	Scenario Information Panel (Right Panel)	172
7.2.5	Available Result Parameters.....	174
7.2.6	Selecting Statistical Measure	175
7.2.7	Statistics Menu (Top Menu Bar)	176
7.2.8	Horizontal Toolbar Functions	177
7.3	Statistical Evaluation and Reporting Tools.....	177
7.3.1	Plots: Scenario (All Data)	178
7.3.2	Plots: Barrier Region (Shapefile)	180
7.3.3	Plots: Barrier Region (Shapefile – Multiple)	184
7.3.4	Number of Rocks.....	184
7.3.5	Number of Deposited Rocks	185
7.3.6	Reach Probabilities	185
7.3.7	Probability of reaching Target Line (SOL)	189
7.3.8	JumpH vs KinEnergy Plot for Target Line	192
7.3.9	Open Trajectories from Shapefile	193
7.4	Trajectory Mode.....	194
7.4.1	Open results in Trajectory Mode	195
7.4.2	Visualize different parameters	196
7.4.3	Working with trajectories.....	198
7.4.4	Rock Trajectory XY Plot.....	199

7.4.5	Line profile	201
7.4.6	Trajectory Data Log File	202
7.4.7	Create All Data Log Files	203
7.4.8	Trajectory Input File	204
7.4.9	Rock trajectory animation.....	204
7.5	Impact Analysis (Terrain or Obstacles)	205
7.5.1	Impact Analysis: Rockfall Sheds (from pts, ASTRA)	205
7.5.2	Impact Analysis: Barrier/Dam/Shed (from pts)	209
7.5.3	Impact Analysis from Shapefile.....	211
7.5.4	ASTRA-Analysis from Shapefile (Terrain)	212
7.6	Forest Information	213
7.6.1	Logfile summary	213
7.6.2	Visualizing trees	213
7.6.3	Tree collision data.....	214
7.7	Exporting Video, Image or GIF animation	215
7.7.1	Video (mp4)	215
7.7.2	Image	216
7.7.3	GIF animation.....	216
7.8	Impact Angles	216
7.9	FULL vs. REDUCED output mode	217
8	References and further reading.....	219
8.1	References.....	219
8.2	Publications	220
9	Third-Party Software.....	225

1 Introduction

RAMMS::Rockfall is a physics-based 3D simulation tool for rockfall hazard assessment. It computes rock trajectories, jump heights, velocities, and energy distributions across complex terrain. The model is designed for site-specific hazard analyses and supports scenario-based risk assessment in engineering practice.

1.1 Motivation

Mitigation of natural hazards relies increasingly on numerical process models to predict the area inundated by rapid geophysical mass movements. These movements include

- snow avalanches,
- torrent based debris flows and hillslope debris flows,
- mudslides,
- ice avalanches and glacier lake outbreaks
- **rockfalls** and rock avalanches.

Process models are used by engineers to predict the speed and reach of these hazardous movements in complex terrain. The preparation of hazard maps is a primary application. The models are especially helpful when proposing technical mitigation measures, such as dams and embankments or rockfall protection barriers. The models allow hazard engineers to optimize limited financial resources by studying the influence of different hazard scenarios on defense options.

1.2 RAMMS

The RAMMS (**RA**pid **M**ass **M**ovements **S**imulation) software system contains five process modules:

- **RAMMS::Avalanche**
- **RAMMS::Debrisflow**
- **RAMMS::Rockfall**
- **RAMMS::Extended**
- **RAMMS::RockIce**

The **RAMMS::Avalanche** and **RAMMS::Debrisflow** modules are designed for flow phenomena containing fast moving particulate debris of snow and rocks. In the avalanche module, the interstitial fluid is air, whereas in the debris flow module the interstitial fluid is mud. The **RAMMS::Avalanche** and **RAMMS::Debrisflow** models are used to calculate the motion of the movement from initiation to runout in three-dimensional terrain. The models use depth-averaged equations and predict the slope-parallel velocities and flow heights. This information is sufficient for most engineering applications. Information in the slope-perpendicular direction (e.g. mass and velocity distribution) is lost; however, this is seldom of practical interest. Both models require an accurate digital representation of the terrain. Engineers specify initial conditions (location and size of the release mass) and friction parameters, depending on terrain (e.g. roughness, vegetation) and material (e.g. snow, ice or mud content of the debris flow).

The RAMMS::Rockfall module is used to study the rigid body motion of falling rocks.

The model predicts rock trajectories in general three-dimensional terrain. Rock trajectories are governed by the interaction between the rock and ground. The model contains six primary state variables: three translational speeds and three rotational velocities of the falling rock. From these, kinetic energy, runout distance and jump heights can be derived. Generalized rock shapes are modeled. Rock orientation and rotational speed are included in the rock/ground interaction. The **RAMMS::Rockfall** module is therefore fundamentally different from **the RAMMS::Avalanche** and **RAMMS::Debrisflow** modules because they are based on hard-contact, rigid-body Lagrangian mechanics, not Eulerian flow mechanics. It also differs from existing rockfall modules because the rock/ground interaction is not governed entirely by simple rebound mechanics, but frictional (dissipative) rock/ground interactions. These govern the onset of rock jumping. **The RAMMS::Rockfall** module predicts all rigid-body motions – rock sliding, rolling, jumping and skipping.

The RAMMS::Rockfall module was coupled to the same user-friendly visualization tool used in the RAMMS::Avalanche and **RAMMS::Debrisflow** modules. The visualization tool allows easy preparation, execution, visualization and interpretation of simulations.

In all **RAMMS modules**, new constitutive models have been developed and implemented, thanks to calibration and verification at full scale test sites such as St. Léonard/Walenstadt (rockfall, mitigation measures), Vallée de la Sionne (snow avalanches) and Illgraben (debris flow).

The **RAMMS** website <https://www.ramms.ch> provides useful information such as more information about the modules, frequently asked questions (FAQ) or recent software updates. Please visit this web page frequently to stay up to date.

RAMMS::Rockfall Model

The **RAMMS::Rockfall** model was developed by the Centre of Mechanics at the ETH Zurich and the RAMMS team of the WSL Institute for Snow and Avalanche Research SLF. This joint project was supported by the Swiss National Science Foundation (Grant: SNF 200021-19613). The Centre of Mechanics was responsible for the development of the simulation code in close contact with geological, geophysical and software engineering experts from the SLF/WSL to discuss modeling issues specific to rockfall mechanics. The SLF/WSL calibrated and validated the simulation code and provided rock shapes. The RAMMS team of SLF/WSL integrated the simulation code in an extensive and easy-to-use graphical user interface (GUI).

Since July 1st, 2024, RAMMS is developed by Marc Christen and Perry Bartelt at RAMMS AG, a WSL-Spin-off in Davos Wiesen, Switzerland.

This manual describes the features of the RAMMS program, allowing beginners to get started quickly as well as serving as a reference to expert users.

1.3 Learning by doing

This manual provides an overview of **RAMMS::Rockfall**. Exercises exemplify different steps in setting up and running a RAMMS simulation especially in Chapter 5 ‘*Setting up a simulation*’. However, to get the most from the manual, we suggest reading it through while simultaneously having the RAMMS program open, learning by doing.

RAMMS::Rockfall is part of the broader RAMMS software suite developed at RAMMS AG for rapid mass movement simulation. It is designed for professional use in hazard mapping, protection measure design, and scientific research on rockfall processes.

DISCLAIMER

The RAMMS software models are provided "as is" without any warranties, express or implied. RAMMS AG makes no representations or warranties of any kind, including but not limited to the accuracy, reliability, completeness, or suitability of the models for any particular purpose.

Users of the RAMMS software models assume all risk associated with the use of these models. RAMMS AG shall not be held liable for any loss, injury, or damage resulting from the use or reliance on these models, including but not limited to personal injury, property damage, or financial loss.

The RAMMS software models are intended to supplement, not replace, the judgment and expertise of professionals in the fields of geology, engineering, and hazard management. Users should not rely solely on the models for making decisions related to hazard mitigation, land use planning, or emergency response.

In no event shall RAMMS AG be liable for any indirect, incidental, special, consequential, or punitive damages arising out of or in connection with the use or performance of the RAMMS software models, even if advised of the possibility of such damages.

Users are responsible for ensuring that their use of the RAMMS software models complies with all applicable laws, regulations, and standards. RAMMS AG does not guarantee that the models meet any regulatory requirements or industry standards.

RAMMS AG may, at its sole discretion, update, modify, or discontinue the RAMMS software models at any time without notice. Users are responsible for ensuring that they are using the most current version of the models.

By using the RAMMS software models, you acknowledge that you have read, understood, and agree to be bound by the terms of this disclaimer.

Swiss law applies. Court of jurisdiction is Davos. If you encounter problems, please contact info@ramms.ch.

2 Installation and Setup

Before installing RAMMS::Rockfall, make sure you have administrative privileges and the license file at hand.

2.1 System Requirements

We recommend the following minimum system requirements for running RAMMS::Rockfall:

- **Operating System:** Windows 10 or higher (64-bit)
(32-bit systems like Win XP are not supported anymore)
- **RAM (memory):** 8 GB (more recommended)
- **CPU:** Intel Pentium 1 GHz (multi core recommended), only 64-bit supported!
- **Graphic Card:** OpenGL support recommended

RAMMS::Rockfall requires a 64-bit Windows operating system with at least 8 GB RAM and a dedicated graphics card for 3D visualization. For large simulation domains or high trajectory counts, 16 GB RAM or more is strongly recommended.

2.2 Installation

Please download the RAMMS::Rockfall setup file "[ramms_rockfall_setup.exe](https://www.ramms.ch/ramms-rockfall/)" from <https://www.ramms.ch/ramms-rockfall/> (Downloads section). Please make sure that you have a 64-bit Windows system.

Please do the following steps before beginning to install RAMMS:

- **Click on the path given above or copy the path to any browser.** A window pops up and the automatic download of the file ramms_rockfall_setup.exe starts after clicking Yes.
- **You must have Administrator privileges on the target machine.**
If you do not have such privileges, the installer cannot modify the system configuration of the machine, and the installation will fail. Note that you do not need Administrator privileges to run RAMMS afterwards.
- **Start the file "ramms_rockfall_setup.exe".** If you need to do a **silent** installation, add -silent when starting the exe-file.

Multilingual Installation

The **RAMMS::Rockfall** installer is designed to support multiple languages, facilitating a user-friendly installation experience for a diverse user base. Upon launching the installer, users can select their preferred language, which will guide them through the installation process in that language.

New Update Procedure

RAMMS::Rockfall incorporates a streamlined update mechanism to ensure users have access to the latest features and improvements.

- **Web Update:** The application can automatically check for available updates online (**Help → Check for Updates**). If an update is found, RAMMS will trigger the download of the new installation file.
- **Users should then exit RAMMS**, and install the new installation file. The installation will remember the last installation location and language.

Administrative Privileges Requirement

To install or update **RAMMS::Rockfall**, administrative privileges are required. This is necessary because the installation process involves modifying system configurations and installing essential components, such as the IDL Visual Studio Merge Modules. Without administrative rights, the installer cannot make these critical changes, and the installation or update will fail.

It's important to note that while administrative privileges are required for installation and updates, they are not needed to run **RAMMS::Rockfall** after installation is complete.

Licensing

RAMMS uses a personal-use licensing model. Licenses are time-limited and bound to a single machine via its unique host ID. To obtain a license, generate a license request file from the target machine and send it to RAMMS AG. You will receive a license key that, once entered, activates full functionality on that specific system.

Alternatively, a license can be installed on a Windows Server and accessed via Remote Desktop Connection (RDC). In this setup, the license can be used by different users, but only one user per module can access it at a time. This setup only works for one license per module.

First-Time Startup and License Registration

When launching *RAMMS::Rockfall* for the first time, a splash screen for the IDL Virtual Machine will appear. Click anywhere on the image to proceed.

2.3 First Start and License Registration

Double-click the RAMMS icon or use **Start** → **Programs** → **RAMMS** → **Run RAMMS** to start RAMMS for the first time. Whenever you start RAMMS, the splash screen below (Figure 2-1) will pop up:

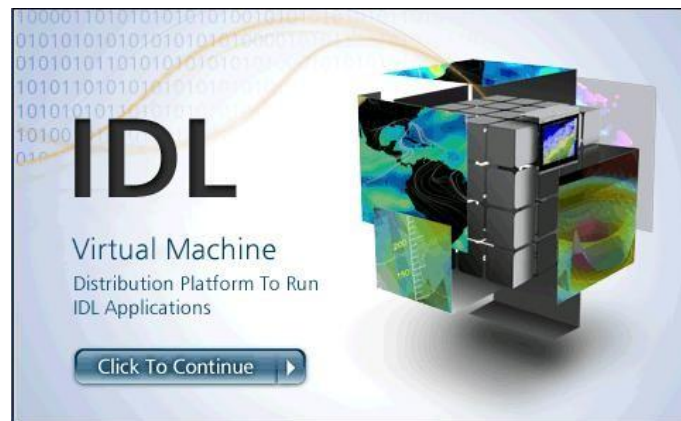


Figure 2-1: RAMMS start window.

Click on the image. It will disappear and RAMMS will start up. You will then see the *RAMMS / Licensing* window (Figure 2-2):

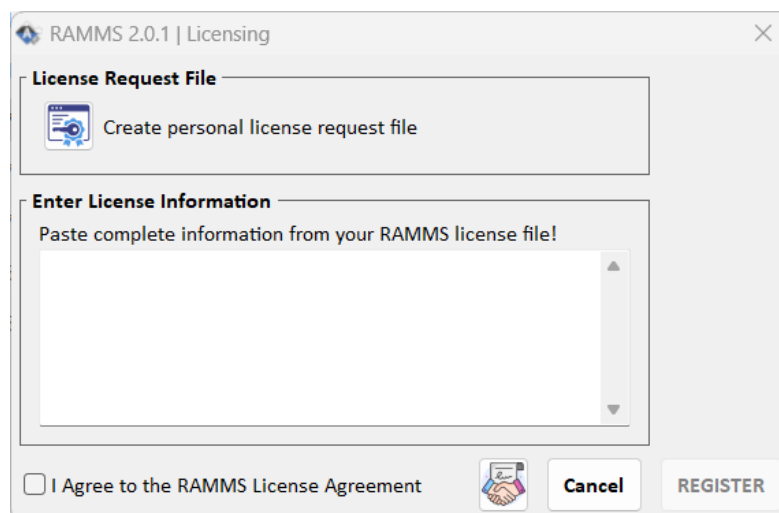


Figure 2-2: Enter the full contents of your license file in this dialog box.

Paste the **full contents** (!!) of your RAMMS license file into the designated field. Check the box to confirm **I Agree to the RAMMS License Agreement**, then click **REGISTER**. To review the license agreement before registering, click the handshake icon.

Create your personal license request file by clicking the top button and follow the instructions.

License Transfer

If you want to transfer your RAMMS license to a new PC, do the following:

- **install RAMMS on the new PC**
- **generate a new license request file**
- **send us the new license request file TOGETHER with your old license file by email**
- **we will then send you the new license file (email)**
- **uninstall RAMMS from your old PC**

Module availability

RAMMS modules can only be used by one user at a time.

If a module is already in use, RAMMS shows the name of the user currently blocking the module.

A module may also remain reserved while a long simulation is running.

If RAMMS is not closed properly, the reservation may remain active for a limited time and is released automatically after the timeout period.

On first launch, RAMMS checks your license information. If a module is already in use, RAMMS shows the name of the user currently blocking the module.

3 The RAMMS::Rockfall GUI

RAMMS uses separate 3D and 2D views. Several input functions — release zones, ground categories, forest parameters, and shapefiles — are only accessible in 2D mode. Familiarize yourself with the toolbar layout and the project/scenario structure before running simulations; each project can contain multiple scenarios sharing the same DEM.

3.1 Starting the Graphical Interface

When RAMMS is launched by double-clicking the **RAMMS::Rockfall** icon,



an initial splash screen is displayed (image below). This screen confirms that the RAMMS application has loaded successfully and is ready to start.

Please note that this splash screen is part of the IDL Virtual Machine startup procedure. RAMMS will not continue to the main interface until the splash screen has been clicked. To continue, click once on the splash screen image.



Figure 3-1: IDL Virtual Machine splash screen

RAMMS will then open the main **Graphical User Interface** (GUI).

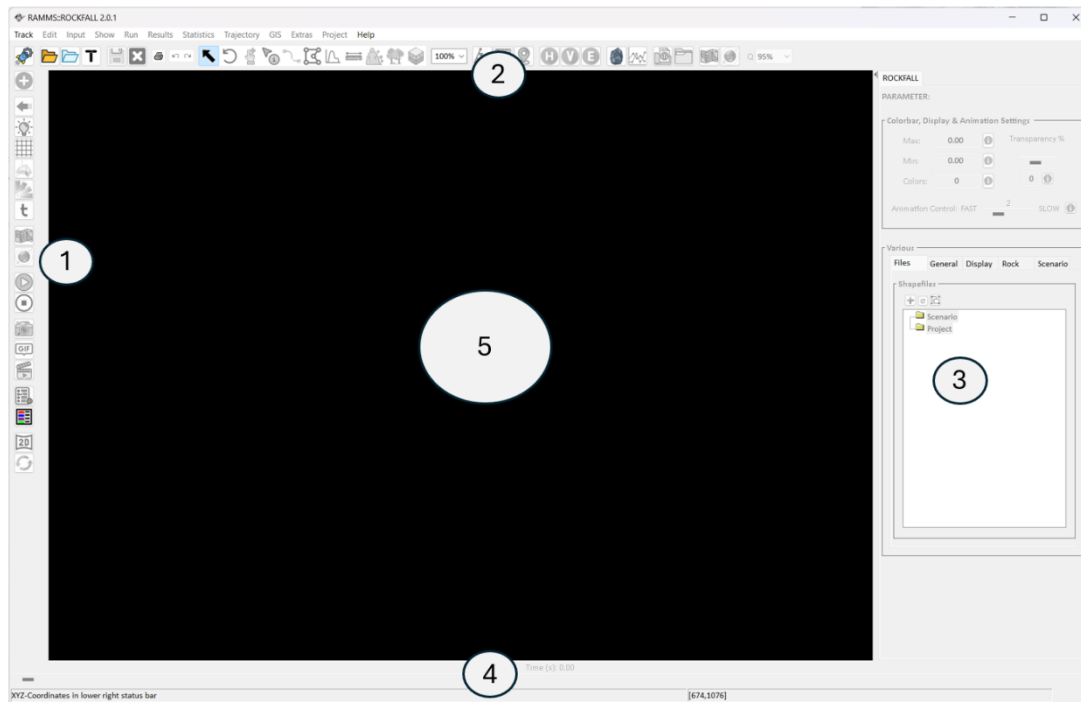


Figure 3-2: RAMMS::Rockfall GUI at startup. The interface is structured into five main regions: (1) a vertical panel on the left side featuring icons for display settings, animations, and preferences, (2) the action toolbar at the top for key functions, (3) the tab field on the right for managing files, (4) the time slider and information displays along the bottom for timeline control, and (5) the central display field for input and output graphics.

The GUI provides a structured and user-friendly workspace. The interface is divided into five distinct regions, see Figure 3-2:

- **Display, Animation and Preference Icons (Left Side):** A vertical list of icons for quick access to display features.
- **Action Toolbar (Top Side):** A horizontal row of icons, including key functions for project management and data input/output handling.
- **Tab Field (Right Side):** A dynamic space for working with multiple tabs, used for file management, user information and display options.
- **Time Slider & Information Displays (Bottom Side):** A timeline control and key important user information.
- **Input/Output Graphics Display:** In this window the input/output graphics is displayed in two-dimensional, or full three-dimensional mode.

At this point, users have **four primary options**, conveniently located in the upper action toolbar:

- **Create a New Project:** Begin a fresh project from scratch.
- **Open an Input File:** Load an existing input dataset for processing.
- **Open a Rockfall Scenario:** Access previously simulated scenarios.
- **Open Rockfall Trajectories:** Access previously simulated trajectories.

Use the Recent option from the menu Track, to load the last active projects. Input files, calculated scenarios or trajectories can be opened after startup.

3.2 Project Creation / Opening Input and Output Files

	Create Project	Creates a project, selects a DEM
	Open Input File	Opens an existing input file
	Open Rockfall Scenario	Opens an existing scenario
	Open Rockfall Trajectories	Opens rockfall trajectories

3.2.1 Project Creation

Every **RAMMS::Rockfall** workflow begins with the **creation of a project**. A project is inherently linked to a specific terrain model, which is defined by a **Digital Elevation Model (DEM)**. To establish a new project, users must consider three essential elements:

- **Project Name:** A unique identifier for the project.
- **Project Location, or Home Directory:** The directory on the user's computer where project files will be stored.
- **Digital Elevation Model (DEM):** A topographical dataset that forms the foundation of the simulation.

Initiating a New Project

To create a **new project**, click the **"Create Project"** icon, located on the upper toolbar. This icon is easily recognizable, featuring a rocket ship in front of a cogwheel. Upon selecting this option, the **Create Project menu** will appear (see Figure 3-3).

The user can also launch the **Create Project Wizard** via the pull-down menu by navigating to **Track → New → Project Wizard** (see Figure 3-3).

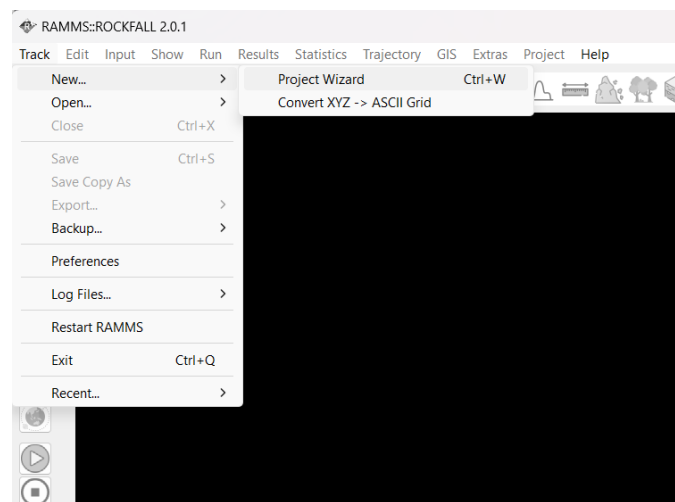


Figure 3-3: Activating the project wizard via pull-down menus.

3.2.2 Understanding the Create Project Wizard/Window

The **Create Project** interface is divided into three distinct sections (Figure 3-4), each serving a crucial role in the project setup process:

- **Project Name & Home Directory (Upper Section)**

- Users must define a project name and select a home directory where all simulation files will be stored.

- **Project Description (Middle Section)**

- This section allows users to input descriptive text about the project.
- While often overlooked, this feature can be highly valuable—especially when revisiting simulations years later. Documenting important details ensures continuity and understanding for future analysis.

- **DEM File Selection (Lower Section)**

- Here, users import the DEM file, which defines the terrain for the simulation.
- Once selected, RAMMS::Rockfall automatically analyzes and reports the DEM resolution, typically 2m or 5m. The Grid Resolution tab in the DEM Input section allows users to adjust the resolution of a DEM to better suit their simulation needs.

To modify the **DEM resolution**, simply click on "**Grid Resolution**", enter the desired resolution, and apply the change. For instance, if the original DEM has a resolution of **0.25 meters**, it can be resampled to a coarser resolution, such as **2 meters**, using **bilinear interpolation**. Similarly, if the DEM resolution is too coarse (e.g., **30 meters**), it can be refined to a finer resolution (e.g., **2 meters**) using the same functionality. This flexibility ensures that the DEM is appropriately scaled for efficient and accurate simulations.

By carefully setting up a project with a clear name, an appropriate directory, and an accurate DEM, users establish a solid foundation for successful simulations in **RAMMS::Rockfall**.

3.2.3 DEM Files *.asc and *.tif

RAMMS::Rockfall supports **two different types of file formats for DEM files**: *.asc and *.tif. The **ASC format**, an ASCII Grid format developed by Esri, is a plain text file that stores elevation data in a structured grid with human-readable values, making it easy to edit but often larger in size. It includes metadata such as cell size, coordinates, and NoData values. On the other hand, the **TIFF format**, specifically GeoTIFF (*.tif), is a

raster format that supports **georeferencing** and can store elevation data in a more compact, binary form. GeoTIFFs are widely used due to their efficiency, ability to store multiple bands, and compatibility with GIS software. While ASC files are simpler and useful for certain applications, GeoTIFFs are generally preferred for large-scale DEM storage and processing due to their superior compression, metadata handling, and performance.

Figure 3-4: The RAMMS::Rockfall Create Project Menu. The menu is divided into three sections. In the upper section a project name and home directory is defined. In the lower section the DEM is specified by the user. In the middle section project information can be inserted.

The **DEM Settings** menu is accessed from the **Create Project** menu (Figure 3-5) and serves two main purposes: **providing key spatial information**—such as the maximum **North, South, East, and West** coordinates—and **allowing users to clip the DEM** if needed.

Clipping the DEM can be done in one of two ways:

- **Manual Coordinate Entry:** Users can manually define the clipping boundaries by entering exact N, S, E, and W coordinates. This is done by activating the corresponding icons in the DEM Settings menu, after which the GUI prompts the user to input the desired values.

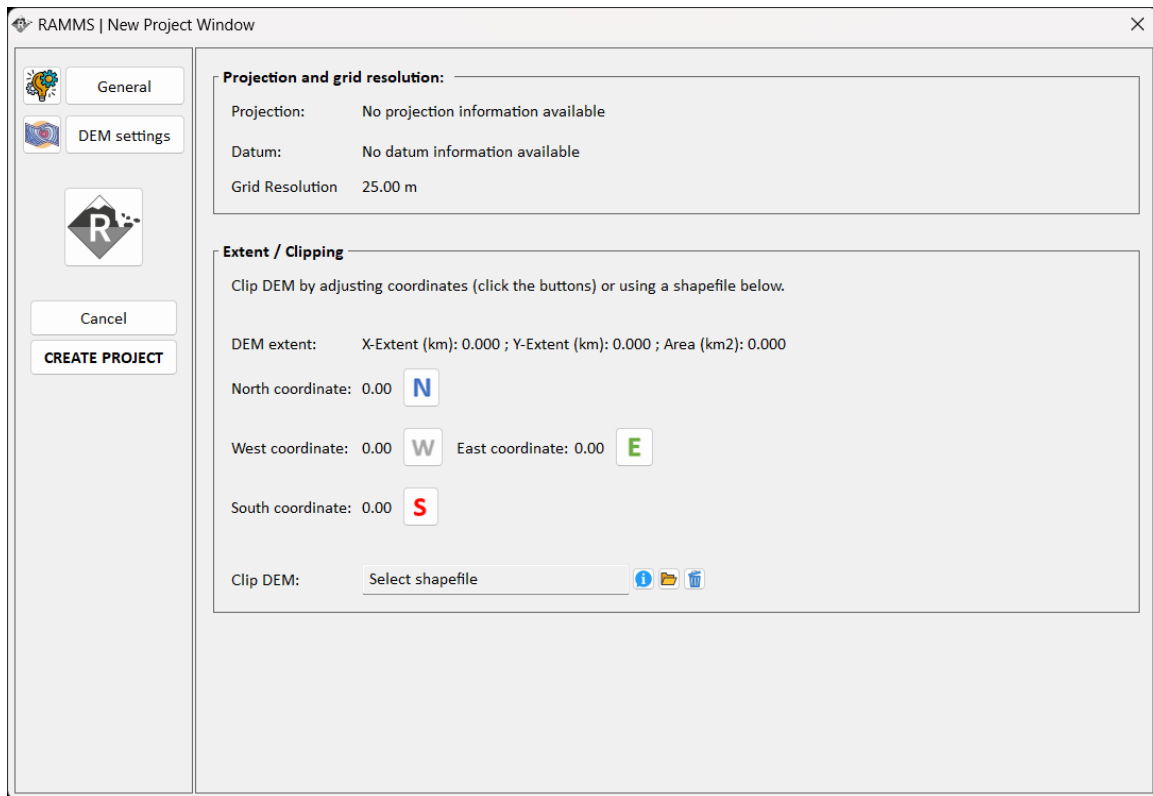


Figure 3-5: The DEM Settings menu. With this menu, the DEM can be reduced by clipping.

- **Shapefile-Based Clipping:** Alternatively, users can clip the DEM using a domain shapefile. This method is often preferred, particularly when refining the computational domain from existing simulations and when a suitable domain file from a previous calculation is available.

By offering these two clipping options, the **DEM Settings** menu provides flexibility in tailoring the DEM to the specific needs of the project.

A RAMMS project links a DEM to one or more scenarios. Each scenario stores its own release zones, ground categories, and rock parameters independently. Use meaningful project and scenario names from the start — renaming later can break file references.

4 Theory

RAMMS::Rockfall models rock motion through coupled translational and rotational equations of motion. Terrain interaction is governed by normal and tangential contact forces, Coulomb friction with slip-dependent coefficients, and energy dissipation through rock-ground scarring. A DEM resolution of 0.5–5 m is recommended for physically meaningful results.

4.1 Overview

The **RAMMS::Rockfall** model utilizes a hard-contact, rigid-body approach to simulate rockfall trajectories in general three-dimensional terrain (Leine et al., 2013). The program is designed for use by hazard engineers to predict rockfall velocity and runout, supporting hazard mapping and the planning of mitigation measures. Terrain is represented using a high-resolution digital elevation model (DEM), which defines slope geometry and controls rock–ground interaction and trajectory development.

The calculation **engine** and user interface were developed as part of a joint research project between the WSL Institute for Snow and Avalanche Research (SLF) and the Institute of Mechanics at ETH Zurich between 2010 and 2013. RAMMS::Rockfall is the third RAMMS module, following RAMMS::Avalanche and RAMMS::Debrisflow, and offers many of the same user-friendly features. The model was officially released in April 2015 after a period of calibration and application testing.

4.1.1 Modelling Approach

Most rockfall models describe the complex interaction between rock and ground using simplified rebound mechanics (Bourrier et al. 2012; Dorren 2003; Dorren and Seijmonsbergen 2003; Schweizer 2015; Volkwein et al. 2011). In these approaches, rock geometries are simplified (typically spheres or ellipsoids), and rock–ground interaction is parameterized using apparent restitution coefficients to represent bouncing behaviour.

To account for the wide variation in jump distances and heights—even in homogeneous terrain (Glover 2015)—stochastic methods are typically used to define ranges of restitution coefficients. As a result, traditional rockfall modelling is both quasi-deterministic and quasi-stochastic.

In contrast, **RAMMS::Rockfall** applies a hard-contact, rigid-body formulation in which contact forces are applied directly to the edges and corner points of the rock. This approach explicitly accounts for rock shape and orientation during impact and eliminates the need for stochastic rebound parameters.

An independent comparison with Flow-R and Rockyfor3D (Noël et al., 2023) confirmed that this approach provides superior trajectory prediction accuracy for site-specific

analyses in complex terrain. Simpler reach-based models remain more efficient for regional screening applications where high spatial detail is not required.

4.1.2 Rock-Ground Interaction and Motion Modes

In **RAMMS::Rockfall**, rock-ground interaction is parameterized using frictional operators acting at the rock surface. Compared to rebound-based models, this allows a physically consistent representation of impact mechanics.

The model reproduces the four primary modes of rock motion:

- **sliding**
- **rolling**
- **skipping**
- **jumping**

Long and widespread runout is generally associated with the jumping mode, whereas rock stopping requires a transition to rolling or sliding. Modelling all four modes is therefore essential for a realistic and self-consistent hazard analysis.

Controlled real-scale experiments demonstrate that **rock shape class—not mass—is the primary determinant of trajectory variability** on intermediate to long slopes (Caviezel et al., 2021; Ringenbach et al., 2023). Platy rocks consistently travel farther and reach higher bounce heights than equant blocks of equivalent mass on identical terrain.

In RAMMS, the variability of trajectories arises naturally from rock shape and impact orientation. The statistical spread of runout and dispersion is generated by varying initial conditions, rather than by randomizing ground parameters. Ground properties are deterministic and represented by assigned material types. This separation between stochastic initial conditions and deterministic boundary conditions simplifies the construction of engineering scenarios and improves interpretation of results.

The model includes 13 default soil categories:

Surface Soil, Subsoil, Alpine Forest, Talus Vegetated, Talus Fine, Talus Coarse, Talus Blocks, Boulder Field, Mountain Road, Asphalt, Bedrock, River/Swamp, Snow.

4.1.3 Rock Shape and Geological Control

Rock shape, size, and release mechanisms are governed by the geometry of discontinuities such as joints, fractures, bedding, contacts, asperities, and schistosity (Jaboyedoff, 2011). In **RAMMS::Rockfall**, defining representative rock shapes and release orientations is therefore an essential part of the analysis.

The rock body is modeled as a **convex hull polyhedron**, defined by a user-provided point cloud describing the surface geometry. Shapes may be idealized (equant, platy, columnar) or derived from laser-scanned field data. A key advantage of RAMMS is that real rock geometries obtained from laser scans can be directly used, allowing users to develop libraries of representative rock shapes for different geological settings.

The importance of selecting an appropriate shape class cannot be overstated. Misclassification—for example, using equant shapes where platy blocks dominate—can lead to systematic underestimation of runout distance and lateral spread. Where uncertainty exists, it is recommended to run at least two shape scenarios and adopt the more conservative result for design.

Typical relationships between geological setting and rock shape are summarized below.

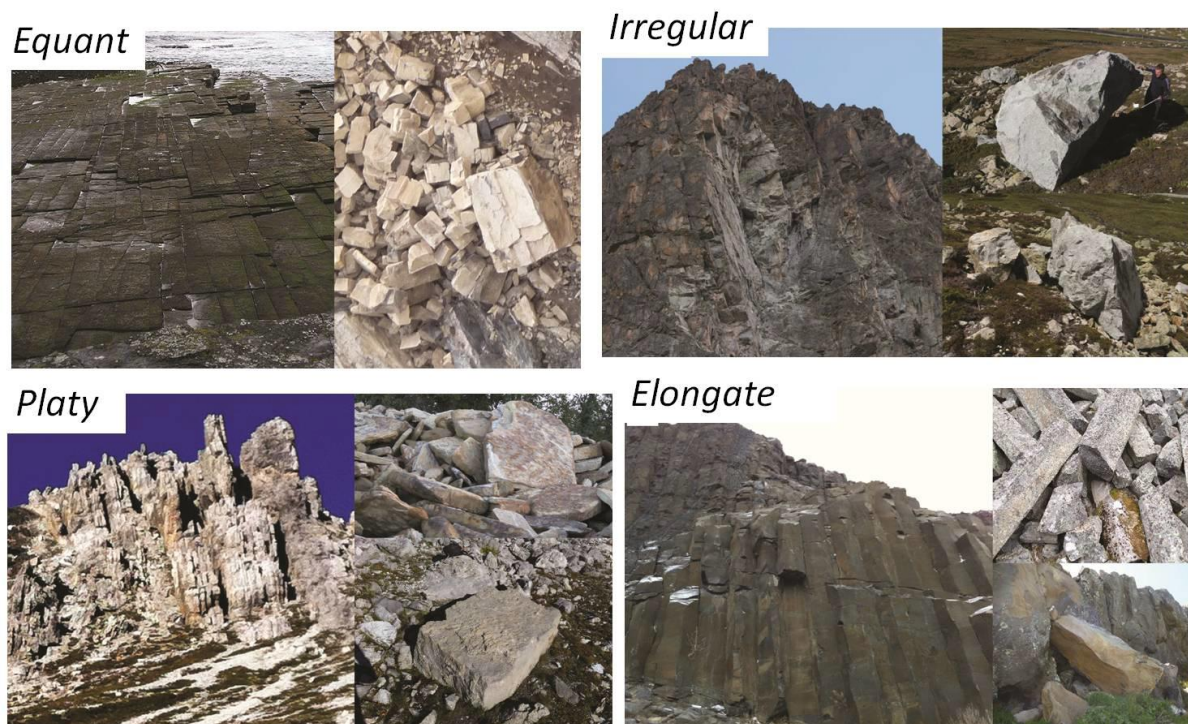


Figure 4-1: Photographs of rock masses and their aggregate forms. Top left: An example of equant cubic rock forms generated in a sequence of sandstones exposed to an extensional deformation regime, the primary joint sets are near equally spaced and orthogonal to one another. Top right: The complex joint of this granodioritic rock mass results in highly irregular and angular rock block forms. Bottom left: The uplifted and folded limestone sequence is well bedded producing distinguished slabs which detach as pronounced platy rock forms. Bottom right: Distinguished columnar jointed basalt sequence produces the characteristic elongate rock forms (Glover 2015).

4.1.4 Rock Fragmentation Considerations

At present, rocks in **RAMMS::Rockfall** are assumed to be **indestructible**, meaning they do not fragment or change shape during simulation. This assumption is appropriate for competent lithologies such as granite, dense limestone, and massive sandstone.

For friable or highly weathered materials—including shale, weathered limestone, and strongly jointed rock—fragmentation during transport is common. Because fragmented

pieces are smaller and dissipate energy more rapidly than intact blocks, the model may overestimate runout distance and impact energy in such cases.

Where fragmentation is expected, it is advisable to simulate additional smaller representative fragment sizes alongside the initial block size.

4.1.5 Rock Rotation and Contact Mechanics

RAMMS::Rockfall explicitly includes rock rotation during both airborne motion and ground interaction. The model accounts for gyroscopic forces, which are essential for reproducing wheel-like skipping and jumping behavior associated with extreme runout.

Rock orientation is tracked using **quaternion algebra**, enabling stable representation of complex rotational motion even when non-linear contact forces alter both translational and rotational movement. This approach allows the full mechanics of an impact to be simulated deterministically, including the computation of moment arms and torques governing the conversion of translational motion into angular momentum.

As a result, rolling, sliding, skipping, and jumping are modelled consistently without reliance on empirical rebound parameters. The three-dimensional motion equations, including rotational effects, are presented in Section 4.3.

4.1.6 Modelling Assumptions and Known Limitations

The **RAMMS::Rockfall** model is based on a number of simplifying assumptions (Table 4.1). These are appropriate for many engineering applications but must be understood when interpreting results and assessing applicability.

Table 4.1: Modelling assumptions and known limitations of RAMMS::Rockfall.
Literature: General rockfall modelling; Noël 2023; Leine 2021; Lu 2019.

Assumption	Practical consequence	Where important
Rock is a rigid, indestructible body	No fragmentation; runout may be overestimated for friable rock	Shale, weathered limestone, strongly jointed rock
Only convex rock shapes are supported	Concave geometries represented as convex hulls; may affect drag torques	Highly irregular, hollow, or concave blocks
Terrain is fixed (no erosion or deposition)	Pre-event DEM used; terrain changes during runout not captured	Soft substrates; large impact scars
Forest soil properties not modified by forest assignment	Ground-level roughness from forest not fully represented	Dense forest on soft ground

Tree destruction is binary (rigid cone, energy threshold)	Transition near destruction threshold is uncertain	Rocks near tree failure energy
Gyroscopic forces derived from initial orientation	Results may be sensitive to initial orientation	Platy and elongated rocks
Aerodynamic drag simplified	Typically negligible; may affect very large, fast blocks	Blocks >100 m ³ at high velocity
DEM resolution limits terrain representation	Sub-grid roughness not resolved	Rough talus, irregular bedrock

4.2 Modeling Rock Shape

The choice of rock shape is one of the most consequential decisions in a **RAMMS::Rockfall** simulation. Caviezel et al. (2021) demonstrate, using controlled real-scale experiments, that shape class — not mass — is the primary determinant of trajectory variability on intermediate to long slopes. Platy rocks consistently travel farther and achieve higher bounce heights than equant blocks of equivalent mass on the same terrain. Ringenbach et al. (2023) confirm this finding and show that the lateral spread of trajectories also increases substantially for elongated and platy shapes.

As a practical guide, the following shape classes are recommended based on the dominant geological setting in Table 4.2.

Table 4.2: : A practical guide to rock shape selection.

Geological Setting	Characteristic Joint Pattern	Recommended Shape Class	Notes
Orthogonal jointing in sandstone / granite	Three near-equal joint sets	Equant / cubic	Symmetric bounce; mean runout representative
Well-bedded limestone / slate	Strong bedding planes, sparse cross-joints	Platy	Long runout; simulate with platy shapes in Rock Builder
Columnar jointing (basalt, some granites)	Prismatic vertical columns	Columnar / elongated	High gyroscopic spin; potential for extreme runout
Highly fractured,	Complex joint network	Irregular equant (use laser-scanned shapes where possible)	High variability; use multiple shapes

irregular masses			
Mixed lithology / variable exposure	—	Use multiple shapes; run separate scenarios	Combine outputs in multi-scenario statistics

Where uncertainty exists about the representative shape, we recommend running at least two shape scenarios (e.g. equant and platy) and reporting results from both. The more conservative result (typically the platy scenario) should be used for protection measure design.

The **RAMMS::Rockfall** model represents **each rock as a rigid, indestructible body**. This is appropriate for competent, massive rock types (granite, dense limestone, massive sandstone). For friable or highly weathered lithologies (shale, weathered limestone, strongly jointed rock), **fragmentation during transport is common**. Fragmented pieces are smaller and lose energy more quickly than the original block, so RAMMS may overestimate runout and impact energy in these cases. Where fragmentation is likely, consider simulating smaller representative fragment sizes in addition to the initial block size.

Rock bodies are introduced into the simulation domain coordinate frame with origin (O) **as a cloud of points based in a coordinate system of their own with origin (K)**. The coordinate frame (K) serves to map the rotations of the rock-body. Points are given in x, y, z format as *.pts files, and can be artificially generated or gathered from a laser scan of rock deposits (Figure 4-2 and Figure 4-3). A convex hull of the rock-body's point cloud is created, in doing so an entirely convex body is created; concavities are closed over in the process. The next step is to calculate the center-of-mass of the body, for which the density is assumed homogeneous. Finally, the inertial tensor of the body is calculated finding the three principal moments of inertia; the origin is the rock's gravity center (S). The translations of the rock-body in the simulation domain are mapped using coordinate frame S in relation to O (Figure 4-3). The rock's mass m is given from its volume calculated from the convex hull of the point cloud and a density ρ which is user defined (typically 2700 kg m^{-3}). The rock has three translational (linear momentum) and three rotational degrees of freedom (spin) to describe the rocks mass center position $q^T = (X, Y, Z)$ at any time t in the terrain coordinate frame O . Rotational motions capture the orientation of the rock's external geometry in space. At time $t = 0$ the rock is released from position $q_0^T = (X_0, Y_0, Z_0)$, which, of course, must be located some distance above the terrain, $Z_0 > Z_m$, and thus the release height h_0 is $Z_0 - Z_m$.

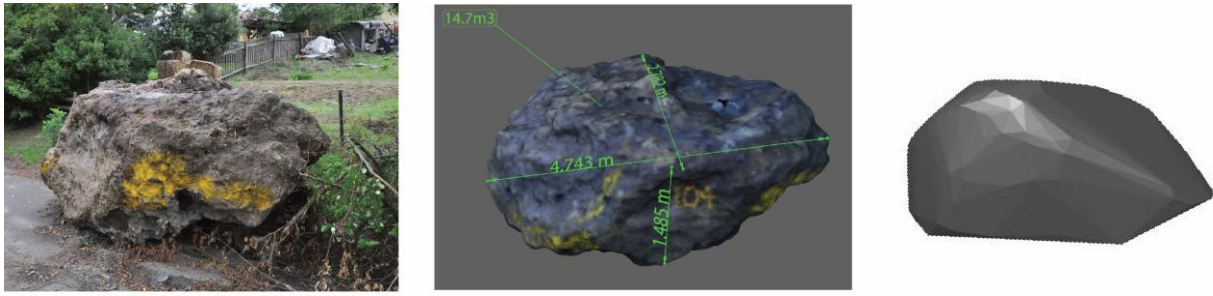


Figure 4-2: Laser scans of real rocks are captured in the field. The point cloud representing the rocks geometry are then used by the rockfall model to create a convex-hull polyhedron representative of the rock-body.

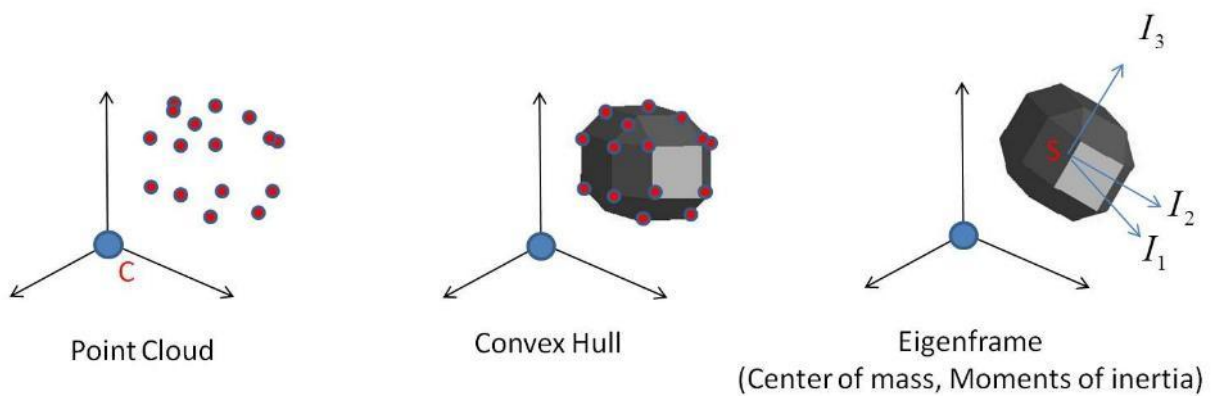


Figure 4-3: Rock is generated from a point cloud and converted into a rigid-body polyhedral.

Rock geometry is represented by a convex hull of the rock-body's point cloud. The shape strongly influences rotational behavior and rebound angles. For calibration, measure the three principal axes of representative blocks in the field.

4.3 Equation of Motion and Free Flight

The general equation of motion for a rock is

$$\mathbf{M}\dot{\mathbf{u}} - \mathbf{h}(\mathbf{q}, \mathbf{u}) = \mathbf{W}(\mathbf{q})\boldsymbol{\lambda} \quad (4.1)$$

where $\mathbf{M}$ is the constant and diagonal mass matrix (containing the mass and three moments of inertia $\mathbf{I}$) and $\dot{\mathbf{u}}$ is the second derivative of the generalized coordinate vector $\mathbf{q}$ (position r_{OS}^I and orientation p_{IK}):

$$\dot{\mathbf{u}} = \frac{\partial^2}{\partial t^2} \begin{pmatrix} r_{OS}^I \\ p_{IK} \end{pmatrix} \quad (4.2)$$

The force term $\mathbf{h}(\mathbf{q}, \mathbf{u})$ contains all gyroscopic terms and finite external forces, such as viscous drag forces, gyroscopic forces, and gravity. The right-hand side of equation (

4.1) consists of the so-called matrix of generalized force directions $\mathbf{W}(q)$ and a vector λ containing all contact forces. Both terms are additions to the equation of motion to account for the contributions of unilateral constraint forces and friction forces during hard contact.

During free flight, only gravity and aerodynamic drag act on the rock. The rotational state (spin) acquired during the previous impact phase is preserved and influences the next terrain interaction. Gyroscopic effects become relevant for fast-spinning or elongated blocks.

4.4 Free Flight Motion with Gravity and Gyroscopic Forces

In free flight, the contact forces λ are zero. The governing equation of motion is therefore reduced to (see Leine et al., 2013)

$$\mathbf{M}\ddot{\mathbf{u}} - \mathbf{h}(q, u) = 0 \quad (4.3)$$

The rock-body's motion is governed by several forces which determine its trajectory. The gravitational force (F_g) acts globally along with gyroscopic forces G which can cause rocks of irregular shape to become upright and rotate about a rolling axis. All force terms $\mathbf{h}(q, u)$ are a function of the rock's position q and velocity u forming the force vector $\mathbf{h}(q, u)$:

$$\mathbf{h}(q, u) = \begin{bmatrix} F_g \\ G \end{bmatrix} \quad (4.4)$$

Gyroscopic forces can cause lateral drift of elongated rocks in free flight, particularly at high rotational velocities. This effect is typically small for compact, rounded blocks but can be significant for platy or rod-shaped fragments on steep slopes.

4.5 Terrain Interaction Phases

To simulate rock-ground interaction, the terrain is divided into a plastic, deformable scarring layer and a non-deformable, hard contact “slippage” plane. Both the scarring layer and the rebound plane are located below the digital elevation model. The interaction between rock and terrain can be summarized in four characteristic phases.

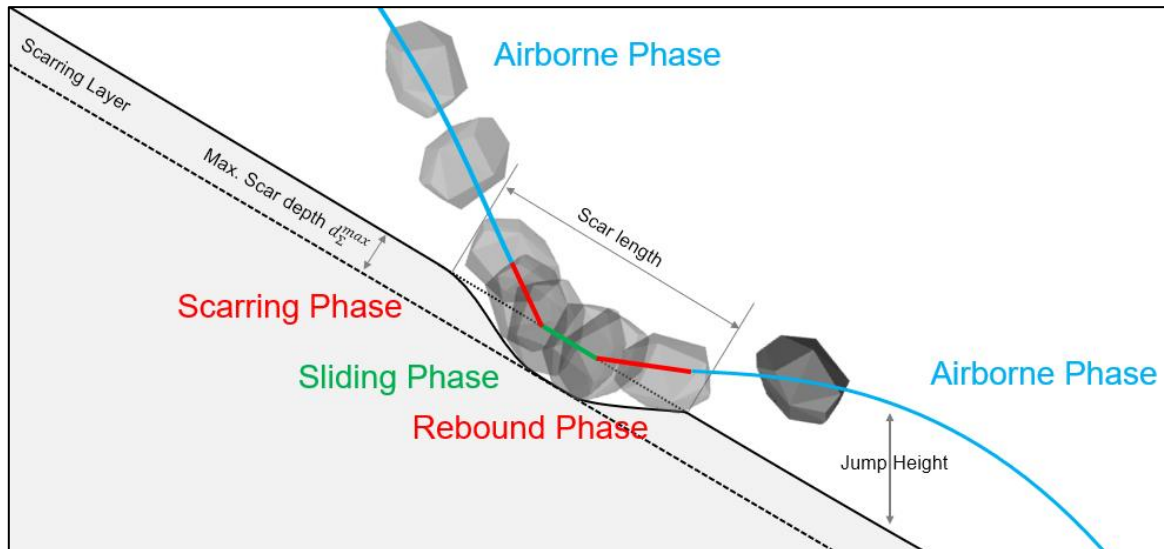


Figure 4-4: The four characteristic phases during the interaction between a rock and compactible soil.

- **Airborne Phase:** The rock is not in contact with the terrain surface. Only gravity and gyroscopic forces are acting during this free flight motion (see chapter 4.3).
- **Scarring Phase:** The rock penetrates the soil. Additional viscous drag forces are acting on the rock due to soil compaction. Soil density continuously increases. Physics during this phase is described in chapter 4.6.
- **Sliding Phase:** The soil cannot be compacted any further by the rock. The compacted soil acts as an infinitely hard frictional plane. We model this phase with a hard-contact approach, which is described in chapter 4.7. The rock then slides on this plane until the friction and eccentricity is so high that the rock stumbles forward and loses contact with the plane.
- **Rebound Phase:** The rock has already changed its moving direction but is still below the terrain surface. Viscous drag forces act on the rock, as soil is pushed in front of it until every vertex of the rock is above the terrain surface, leaving behind a permanent scar.

4.6 Energy dissipation due to rock-ground scarring

4.6.1 Drag Forces

As soon as one vertex of the rock intersects the terrain, the rock starts penetrating the ground. This penetration leads to a compaction of the soil. Due to the generally very fast and high energy process, soil compaction is assumed to be purely plastic. The fine particles of the soil act similarly to a fluid and exert a drag force against the rock motion [De Blasio et al., 2018]. The soil resistance force on the rock is modelled with a velocity squared resistance law parameterized by the scarring coefficient C_d , which is equivalent in form to drag defined in fluid dynamics:

$$F_T(t) = \frac{1}{2} C_d \rho A(t) \|v_T(t)\|^2 \quad (4.5)$$

Where $A(t)$ is the cross-sectional area of the penetration scar at time t , ρ is the soil density and $v_T(t)$ is the translational velocity of the rock at time t . This viscous drag force $F_T(t)$ acts on the center of mass of the rock in opposite direction to the velocity vector, see Figure below.

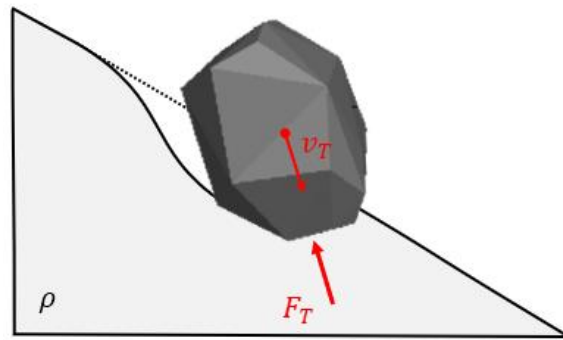


Figure 4-5: Viscous drag force $F_T(t)$ acting against translational velocity vector $v_T(t)$.

This force generally increases during an impact, because the cross-sectional area of the penetration scar $A(t)$ increases as the rock goes deeper into the scar.

4.6.2 Drag Torques

Due to partial immersion (eccentricity) and rotational velocity of the rock into the soil, there is an additional rotational drag torque acting. This torque consists of two parts:

Translational torque occurs due to the translational velocity of the rock combined with an eccentricity due to partial immersion. The corresponding forces F_T and torques τ_T referring to Figure 4-6a are:

$$F_T(t) = \frac{1}{2} C_d \rho A_T(t) ||V_T(t)||^2 \quad (4.6)$$

$$\tau_T = -F_T \times d \quad (4.7)$$

The translational drag force always acts on the center of mass of the submerged rock and in opposite direction of the velocity vector. The cross-sectional area A_T is always normal to the velocity vector. Depending on the impact configuration and rotational velocity of the rock, the translational torque may act in direction of the current rotational velocity vector or against it.

Rotational torque occurs due to the rotational velocity of the rock during scarring. Due to its spin, the partially submerged rock feels a resistance force perpendicular to the plane spanned by its rotational velocity vector and the connecting vector between its center of mass and the center of mass of its submerged part. The corresponding forces F_Ω and torques τ_Ω referring to Figure 4-6b are:

$$F_\Omega(t) = \frac{1}{2} C_d \rho A_\Omega(t) ||V_\Omega(t)||^2 \quad (4.8)$$

$$\tau_\Omega = -F_\Omega \times d \quad (4.9)$$

The rotational drag torque always acts on the center of mass of the rock and against the rotational velocity vector.

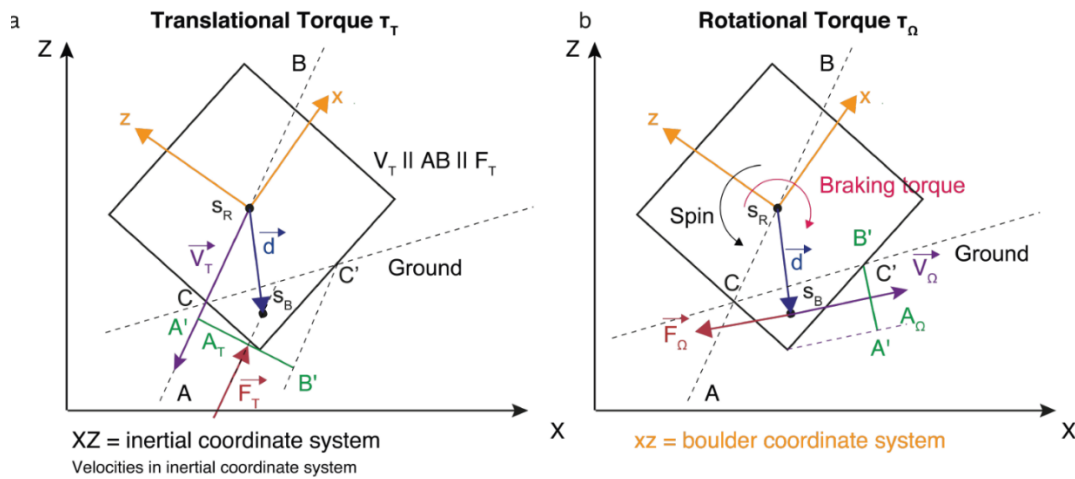


Figure 4-6: Two types of drag torques acting on the rock during scarring. s_R is the center of mass of the rock. s_B is the center of mass of the submerged part of the rock.

4.6.3 Maximum penetration depth

As the rock enters the terrain, the soil density increases due to soil compaction. Due to this, it evidently also approaches the point where the rock cannot compact the soil any further. This point marks the depth of the scarring layer. From this point on, the soil is treated as an infinitely hard, non-deformable plane (see chapter 4.7). The rock has reached the maximum scar depth. This scar depth is a function of the compressibility

of the soil, the mass of the rock and its velocity. To this end, Gerber (2019) proposed a rock penetration equation obtained through fitting the experimental data for freely, vertically dropped rocks of various masses, soil types and initial heights, and considering Hertz theory for the contact forces calculation. This formula reads as follows:

$$d_{max} = 0.16 M_r^{0.25} M_E^{-0.4} ||V_{\perp}||^{0.8} \quad (4.10)$$

Where d_{max} is the maximum scar depth [m], M_r is the mass of the rock [kg], M_E is the mechanical strength of the soil [kPa] and $V_{\perp}$ is the terrain perpendicular component of rock velocity [m/s] right before it touches the terrain.

4.7 Hard Contact and Slippage

4.7.1 Contact forces

On contact detection between the rock-body and the rebound plane, contact forces λ and frictional contact forces (F_c) act about the point of contact. These forces can be considered as external forces that change the direction of the falling rock.

The contact of the rigid rock-body is detected by continually measuring the vertical gap length g_N between the rock-body's corner points (P) and the rebound plane's projections (Q) (Figure 4-7). The gap length is defined as

$$g_N(X, Y, Z) = Z - Z_m(X_m, Y_m) \quad (4.11)$$

Then, when $g_N > 0$, there is no contact and the contact forces λ acting at the contact point P are computed. (The contact forces are denoted using the Greek letter lambda because the contact forces are Lagrangian multipliers that enforce the non-penetration constraint). Minimal penetration with the terrain is permitted to allow the assessment of the contact condition (Eq. 3.3). This is a non-physical penetration and purely for numerical purposes.

Contact forces are modeled as hard unilateral constraints with Coulomb friction using non-smooth contact dynamics approaches (see Acary and Brogliato, 2008, Glocker, 2001 and Moreau, 1988). For the case of contact, the governing equations of motion now become

$$M\ddot{u} - h(q, u) = \lambda W(q) \quad (4.12)$$

where the direction of the contact forces is given by $W(q)$. There can be several active contact forces depending on the rock-body's configuration at the point of contact. Ultimately it is the combination of these forces λ (and force directions $W(q)$) that allows the complex rotations and trajectory deviations that are inherent to rockfall to be simulated.

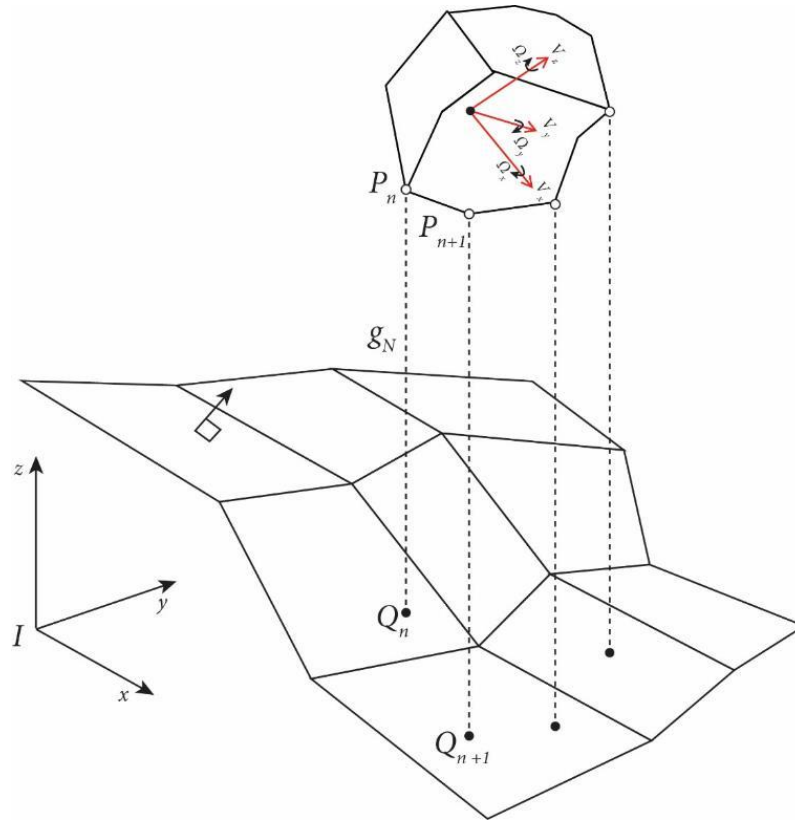


Figure 4-7: Contact detection. Definition of gap length, g_N .

The advantage of this *hard-contact* rigid-body approach is that the contact forces are applied directly at these contact points, respecting the configuration (orientation and kinetics) of the impact. This is achieved by considering the contact pair (Q, P) within the contact frame $\mathcal{C} = (n, t_1, t_2)$ which is attached to the terrain surface at contact point Q (Figure 4-8).

4.7.2 Friction forces

The contact frame $\mathcal{C}$ has a normal contact force component λ_N and two tangential components $\lambda_{T1}, \lambda_{T2}$. The contact force λ_N guarantees the unilaterality of the contact, i.e., the non-penetration constraint. The tangential force components are due to Coulomb friction and are governed by the contact laws.

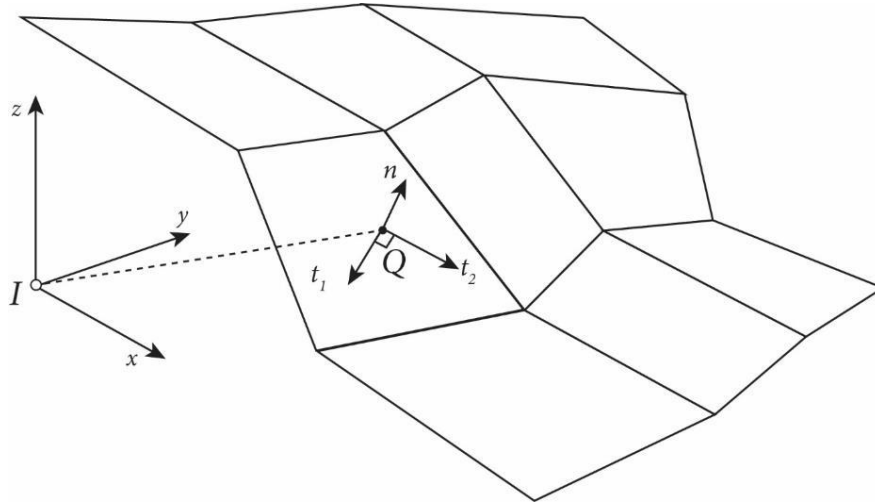


Figure 4-8: Contact frame C at point Q detected with the gap function g_N .

The normal force component λ_N is resolved with a contact cone differential inclusion, in which the transient normal force vector over the finite contact period can be computed. Over the contact period this is a set-valued normal force considering all periods of contact identified with the gap function g_N .

The tangential force component λ_T is assumed to obey spatial Coulomb's friction law (see Figure 4-9). Stiction of the contact $\gamma_T = 0$ occurs as long as the magnitude of the tangential force $\|k\lambda_T\|$ is less than $\mu\lambda_N$, in which λ_N is the applied normal force and μ the friction coefficient. The direction is also resolved with a normal cone inclusion projecting a friction disc on to the surface (Figure 4-9). The formulation covers both sticking and sliding cases.

4.7.3 Impulsive forces (Rebound)

Impulsive contact forces occur whenever the gap function detects contact with negative velocity $\gamma_N^- < 0$, where the point would theoretically move through the rebound plane if not treated with the impulsive contact force. This requires a velocity jump such that the post impact normal velocity is non-negative $\gamma_N^+ > 0$. This impact law is based on Newtonian impact law in which the relative normal velocities of the contact pair before and after impact are governed by ε_N the normal restitution coefficient. $\varepsilon_N = 1$ corresponds to complete restitution of normal velocity while a smaller ε_N dissipates energy. This value is set to zero. Newton's action-reaction law is always fulfilled.

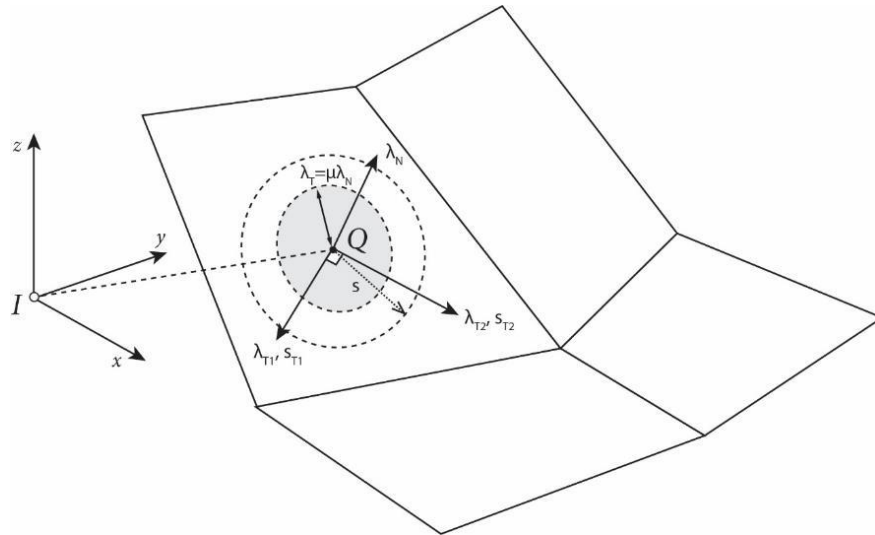


Figure 4-9: Friction forces at the contact point.

$$\gamma_N^+ + \varepsilon \gamma_N^- = 0 \quad (4.13)$$

Impulsive normal forces can also induce impulsive tangential forces. While this is mainly seen in the elastic impacts of superballs (Cross, 1999), and therefore in the rockfall model ε_T is set at $\varepsilon_T = 0$ since these effects are absent.

To determine the resultant force direction acting on the rock-body the configuration of the impact must be computed. This requires finding the relative velocity between the contact points P and the terrain Q . Importantly, the velocity of contact point P is composed of the translational velocity with respect to the body's center of mass and its angular velocity in the fixed body frame (K); for which P also has a fixed position vector relative to the center of mass S . That is, the contact algorithm in the rigid-body approach considers the rotational speed of the rock at contact. Because the forces are then applied at points away from the center of mass, and with a direction respecting the impact configuration to a body with three degrees of translational and rotational freedom, torques and moment, arms can act generating rotations and rebounds that represent the true mechanics of an impact.

4.7.4 Contact Friction

Two different physical forces oppose the motion of a falling rock: sliding friction and drag. Sliding friction acts at points of the rock's surface that are in contact with the rebound plane; it is Coulomb-type friction associated with the distance the rock slides on the ground. When the rock is no longer in contact, this friction no longer acts. However, because this friction acts on a point on the rock's surface, it will generate torques that initiate rotational movements. The parameterization of the friction force is of great importance because it controls when the rock slides, rolls or jumps. Drag forces in the **RAMMS::Rockfall** model account for the viscoplastic drag due to terrain deformation (scarring) during ground contact. These forces are described in section

4.6. They act not only in the scarring phase (when the rock moves in the ground), but also in the sliding phase, when the underlying ground has reached its maximum density and acts as an infinitely hard rebound plane. This is because even though the rock does not penetrate further into the ground, it still pushes the soil in front of it and thus experiences a resistance force.

4.7.5 Coulomb Friction and Slippage

The mechanical contact law considers hard contacts between the rigid body and the rebound plane.

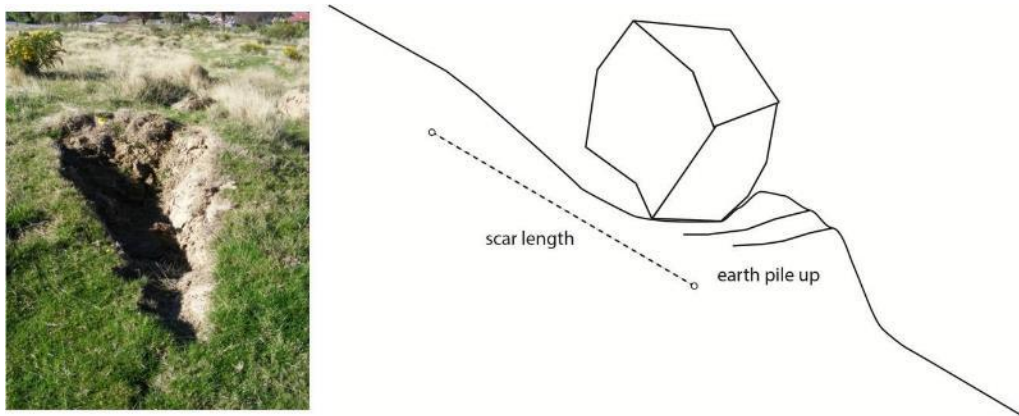


Figure 4-10: Rock impact scar in soft soil, tapering and widening toward an earth accumulation at the distal end, where a ramp forms; modeled as increasing (climbing) friction from first contact ($s = 0$) to the scar end.

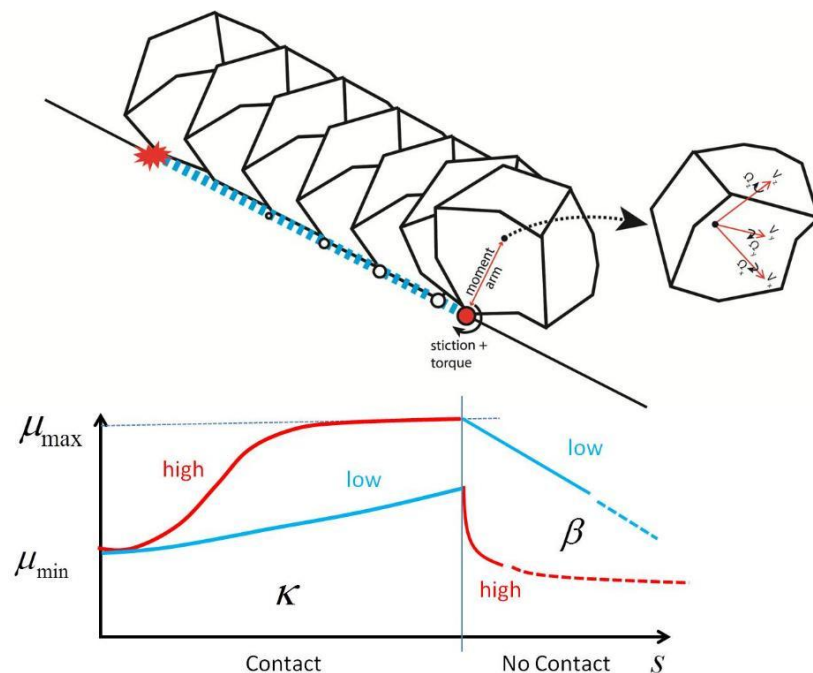


Figure 4-11: Sliding friction on the rebound plane in RAMMS follows a slip-dependent law: at impact ($s = 0$), friction is μ_{min} ; it increases with slip (κ) to μ_{max} , then decays exponentially (β) as the rock leaves the scar.

The hard contact friction uses a slip (s) dependent friction that acts during sliding and accounts for the increase in friction due to material accumulation behind the rock-body as it slides on the rebound plane (Figure 4-10 and Figure 4-11). The slip dependent friction is an extension of the Coulomb friction model in which the friction value μ is made dependent on the slip distance (s) travelled by the center of mass $\mu(s)$ (Figure 4-11).

Moreover,

$$\lambda_T = \mu(s)\lambda_N \quad (4.14)$$

force λ_N enforces the non-penetrability constraint; the force λ_T acts tangentially on the terrain surface (see Figure 4-9). The dependence of the friction coefficient on the slip distance (s) is:

$$\mu(s) = \mu_{min} + \frac{2}{\pi} (\mu_{max} - \mu_{min}) \tan^{-1}(\kappa s) \quad (4.15)$$

where μ_{min} , μ_{max} and κ are parameters of the friction model. The initial friction encountered at the contact where $s = 0$ is μ_{min} . Over the slip period, $\mu(s)$ tends toward μ_{max} for large slip values, see Figure 4-11. The parameter κ controls how quickly the friction increases from μ_{min} to μ_{max} . Typically, $\mu_{min} < \mu_{max}$ meaning that the friction increases the longer the rock is in contact with the rebound plane. It is entirely possible that there are brittle ground materials where the opposite behavior ($\mu_{max} > \mu_{min}$) is encountered.

The slip distance (s) is a transition state variable having a time evolution which is described by a simple differential equation:

$$\dot{s} = \begin{cases} \|v_s\| & \text{if } g_N \leq 0 \\ -\beta s & g_N > 0 \end{cases} \quad (4.16)$$

The parameter β controls how quickly the friction is released as the rock departs the ground scar. If β is large, friction is immediately removed as the rock moves away from the rebound plane. Conversely, when β is small, sliding friction can act, even after the rock is no longer in contact with the rebound plane.

4.8 Terrain/Soil Material

The **soil material** has considerable influence on the simulation result. Shapefiles are used to delimit terrain areas with specific soil materials. The main predefined soil categories are described below.

Surface Soil

Category	Picture	Description	Example
Surface Soil		Rocks penetrate meadow surface leaving impact scars. Soil is deep, with few rock sediments. Rank vegetation. The proposed parameters apply only to regions where surface soil is deep (and followed by subsoil). Rock scars exclusively in soil.	Meadow/ grassland

Subsoil

Category	Picture	Description	Example
Subsoil		Penetration depths are small. Ground is flat. Rocky debris is present. Shallow surface soil. Usually little (initial) vegetation. Well vegetated moraine/scree (10-20cm).	Non-paved mountain roads, mountain meadow

Alpine Spruce/Beech Forest

Category	Picture	Description	Example
Alpine Spruce/Beech Forest		Forest soil, calibrated from rockfall tests in forests in Schiers, Switzerland	Forest

Vegetated Talus

Category	Picture	Description	Example
Vegetated Talus		In between pure fine talus and well vegetated moraine/scree (subsoil)	Vegetated talus scree

Talus Fine

Category	Picture	Description	Example
Talus Fine		Rocks jump over ground. Mostly small rocks. Usually without any vegetation. Q95 grain size $\leq$ 5cm, median grain $\leq$ 2cm	Rock scree, pebble sediments

Talus Coarse

Category	Picture	Description	Example
Talus Coarse		Rocks jump over ground. Mixture of large and small rocks. Usually without any vegetation. Q95 grain size $\leq$ 20 cm, median grain $\leq$ 10 cm.	Rock scree, pebble, coarse rock, paved roads

Talus Blocks

Category	Picture	Description	Example
Talus Coarse		Rocks jump over ground. Can get stuck. Mostly large rocks. No vegetation. Q95 grain size ≤ 50 cm, median grain ≤ 30 cm.	Large rocks

Boulder Field

Category	Picture	Description	Example
Boulder Field		Tends to be composed of larger rocks and boulders. DEM should include this roughness. If not, increase C_d .	Rocks and boulders

Bedrock

Category	Picture	Description	Example
Bedrock		Ground is very hard and is marginally deformed by rocks. No vegetation and no surface soil.	Bedrock, cliff

River/Swamp

Category	Picture	Description	Example
River/Swamp		River or very wet ground. Cannot cross without deep sink-in. No high vegetation. Rock's stop immediately. Does not correspond to the "Extra Soft" from Version 1.7.65.	Moor, turf, swamp, river

Based on the physical model of **RAMMS::Rockfall** described in the previous chapters, different soil types can be distinguished by the following properties:

Scarring **properties (see chapter 4.6):**

- **Soil strength M_E**
- **Drag coefficient C_d**

The hard contact properties described in section 4.7 are the same for all soil types. This results from the model assumption that all soil types have similar properties when the soil is compacted to its maximum density. This also has practical reasons. The hard contact model has many degrees of freedom and friction parameters that are not intuitive in practice. Therefore, different soil types are distinguished entirely by their scarring properties and not during the hard contact. The hard contact properties are set to:

Table 4.3: Hard contact properties for all soil types used in the coulomb friction model (see equations (4.13), (4.15) and (4.16)).

μ_{min}	μ_{max}	β	κ	ϵ
0.55	2	185	3	0

Soil material is assigned through shapefiles defining ground categories across the simulation domain. Each category requires M_E - (soil strength) and C_d -values (drag coefficient). Use the RAMMS default parameter tables as a starting point, then calibrate against local observations.

4.8.1 Soil Strength M_E

The soil strength M_E is a geotechnical parameter that describes the amount of pressure that needs to be applied to achieve a certain amount of strain (or settlement over a certain soil thickness). The unit of M_E is therefore N/m² or Pa. Other terms for M_E are Oedometer modulus or compressibility modulus (in German: Steife-/Zusammendrückungsmodul). In the **RAMMS::Rockfall** model, M_E serves a similar purpose. It is used to describe the scar depth of a rock with given mass and velocity in a particular soil, according to the empirical formula introduced in chapter 4.6, equation 4.17:

$$d_{max} = 0.16 M_r^{0.25} M_E^{-0.4} ||V_{\perp}||^{0.8} \quad (4.17)$$

The higher the M_E value is for a soil, the lower the scar depths of rocks and thus also the energy dissipation during soil interaction. In other words, the stiffness of the soil increases with the M_E value.

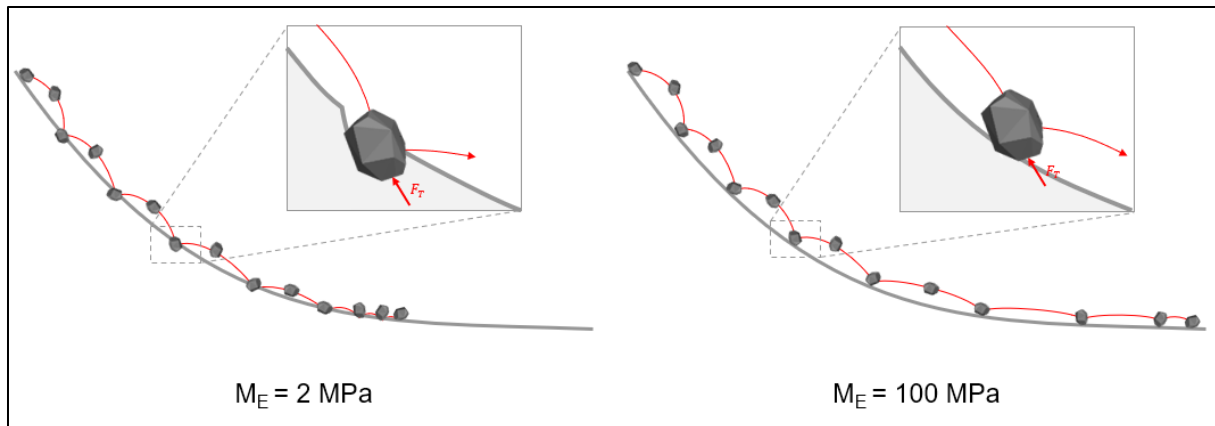


Figure 4-12: Changing M_E influences the scar depth (and thus the runout) of rocks.

The M_E value in **RAMMS::Rockfall** is closely related to the M_E value used in geotechnical engineering to increase the understanding of how it affects soil behaviour during rock-soil interaction. However, it should be noted that **RAMMS::Rockfall** uses this parameter in an empirical relationship that is part of a simplified model calibrated with real scale rockfall experiments. We therefore do not recommend determining this parameter with oedometer tests in the laboratory, as is common in soil mechanic's practice. We strongly advise to use our recommended and calibrated standard parameters as a first approach, to perform plausibility checks by analysing the scar depths of the resulting simulations and to adjust the value accordingly. Realistic values in alpine terrain lie between 1 MPa and 200 MPa.

See example scar depths from rock-sizes, M_E -values and velocities below (Figure 4-13, Figure 4-14 and Figure 4-15).

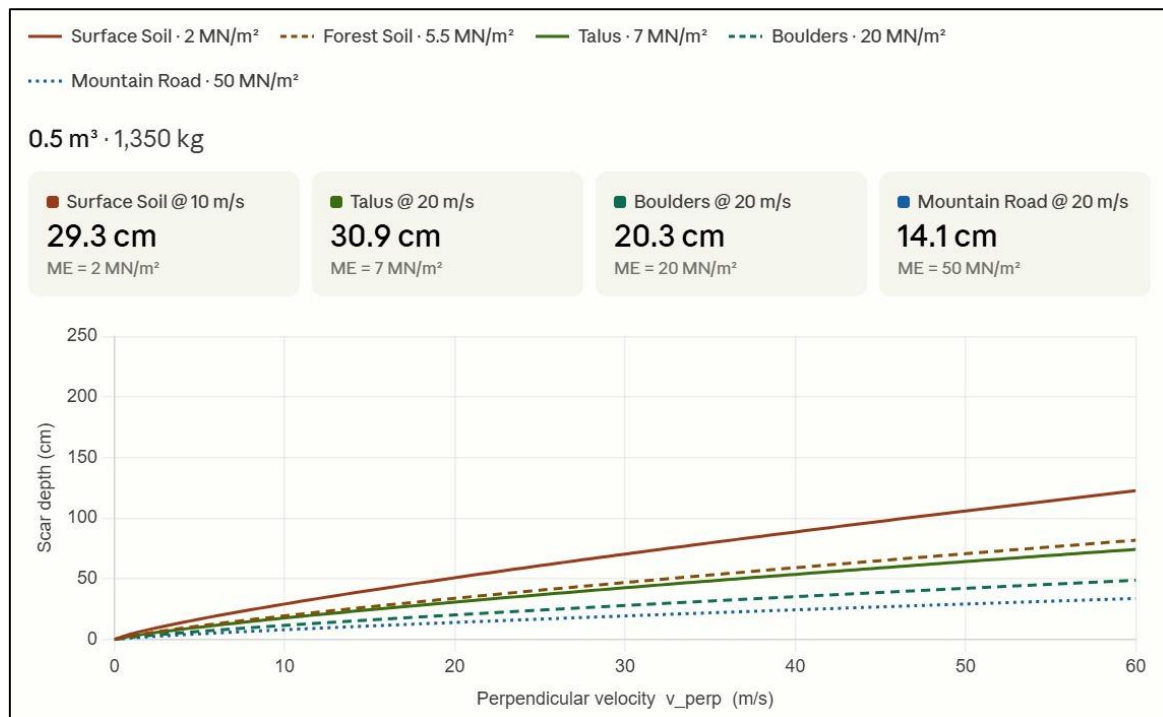


Figure 4-13: Scar-depths for a 0.5 m^3 rock

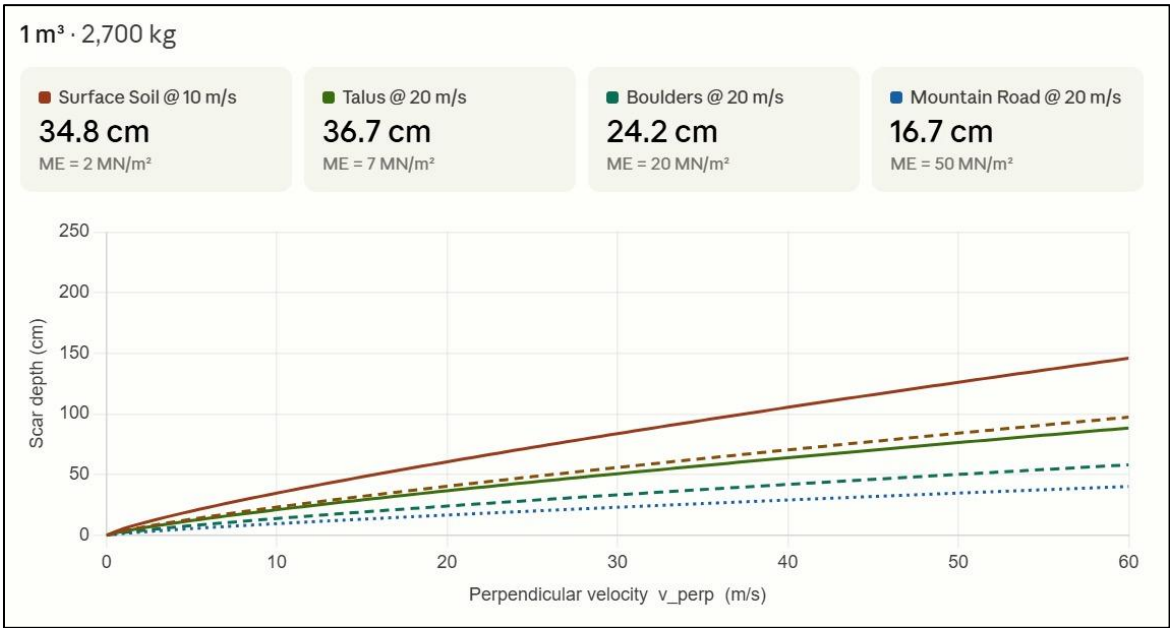


Figure 4-14: Scar-depths for a 1m³ rock

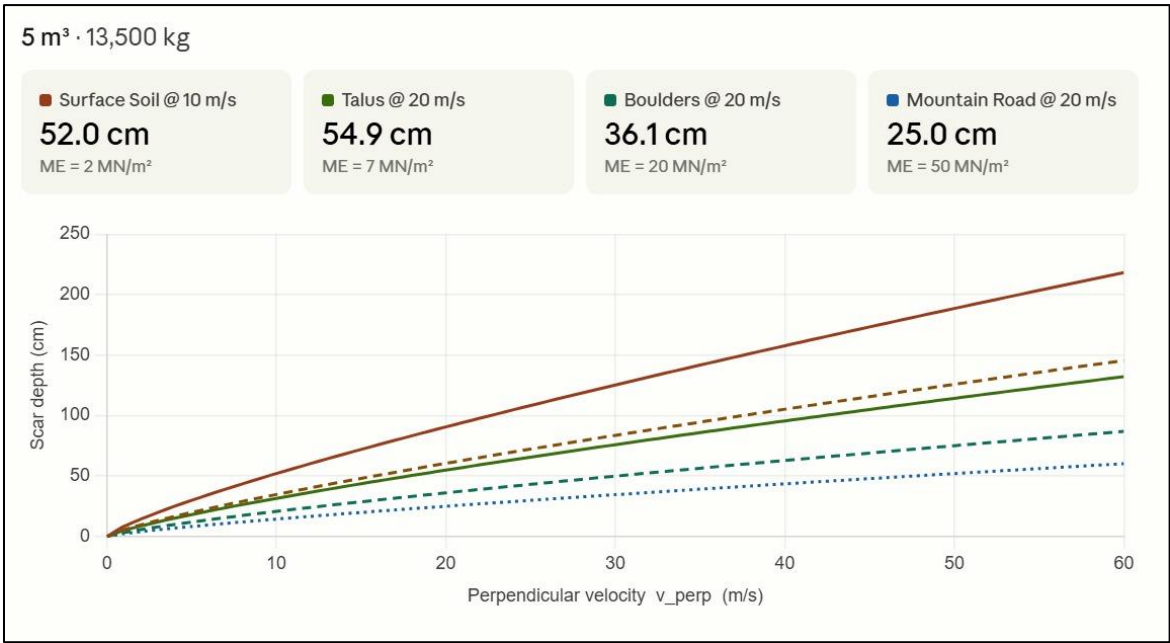


Figure 4-15: Scar-depths for a 5m³ rock

4.8.2 Drag Coefficient C_d

The drag coefficient influences the viscous drag force that the rock experiences during soil interaction (see chapter 4.6):

$$F_d(t) = \frac{1}{2} C_d \rho A(t) \|v(t)\|^2 \quad (4.18)$$

The higher the drag coefficient C_d of a soil, the higher the resistance force and the higher the energy dissipation during ground contact. Note that C_d does not affect the scar depth.

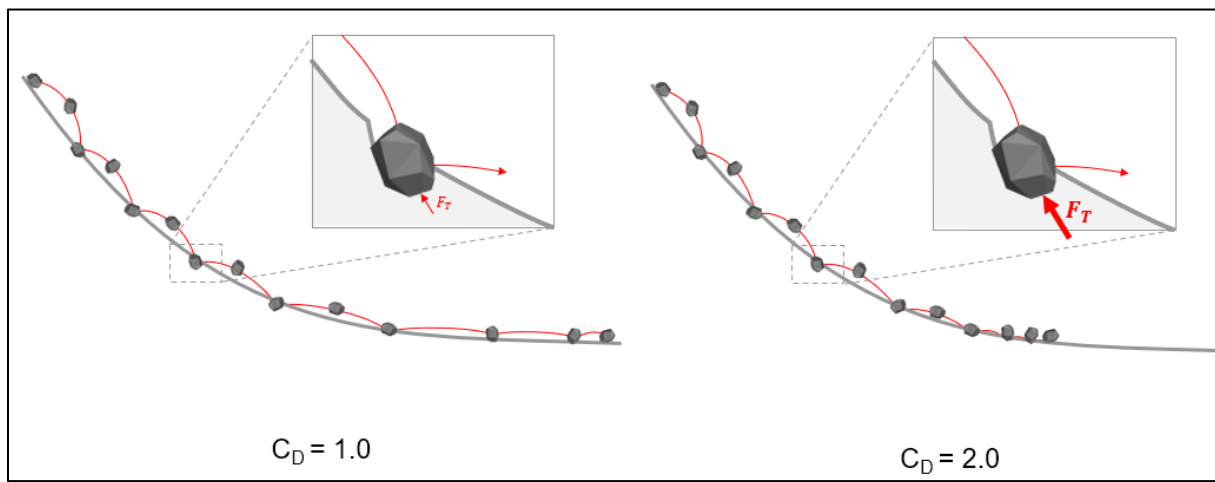


Figure 4-16: Changing C_d influences the resistance force during scarring and therefore the runout distance of rocks.

The coefficient originates from hydrodynamics for the calculation of a resistance force of an obstacle in a viscous fluid. It is a dimensionless, empirical coefficient that summarizes the effects of the object shape and material viscosity on the drag force.

RAMMS::Rockfall adapts this concept with the modelling assumption that due to the high energy impact of rocks and the inelastic behavior of soil, the soil particles behave like a fluid around the rock. Realistic values for the drag coefficient in alpine terrain are between 1 and 10. **RAMMS::Rockfall** offers various default soil categories which are calibrated with real-scale experiments:

Table 4.4: Scarring properties of all default soil types.

Category	M_E [MPa]	C_d [-]
River / Swamp	0.2	1000
Surface Soil	3	1.55
Subsoil	4	1.8

Alpine Spruce/Beech Forest	5.5	1.2
Talus Vegetated	6	2.1
Talus Fine	7	2.3
Talus Coarse	10	2.7
Talus Blocs	15	3.5
Boulder Field	20	3.5
Mountain Road	50	2
Asphalt	75	2
Bedrock	100	4
Snow	0.1	1

4.8.3 Terrain conditions vs. selected terrain category vs. rock size

In previous versions of **RAMMS::Rockfall**, we suggested changing the ground categories depending on the rock size, to consider the additional energy dissipation when a large rock scars, compared to the scarring of a small rock. With the new scarring model, this is now not necessary anymore because the scar depth is automatically determined from the rock mass, velocity, and soil strength (see equation (4.18). A larger rock will therefore automatically scar deeper and thus lose more energy.

4.8.4 Calibrating the ground parameters

The default soil parameters in Table 4.4 provide a reliable starting point for sites where no local observational data are available. In practice, however, site-specific calibration against documented field evidence substantially improves the reliability of **RAMMS::Rockfall** predictions. This section describes a structured calibration workflow applicable when one or more historical events can be used as reference.

Step 1: Collect field evidence

Before adjusting any parameters, compile all available field observations at the calibration site. The following types of evidence are most useful for calibrating

RAMMS::Rockfall:

- **Deposition points:** GPS-surveyed endpoints of observed blocks, or mapped deposit clusters. These constrain the maximum runout distance of the reference event.
- **Bounce height indicators:** Height of tree scars, bark abrasion marks, or impact marks on vertical surfaces (cliff faces, building walls). These directly constrain the jump height output.
- **Scar morphology:** Length and depth of impact craters on soft terrain. These calibrate the M_E parameter via equation (4.20).
- **Lateral spread:** The observed width of the affected corridor, which constrains release configuration and terrain channelling.

Where field evidence is absent, silent witnesses (absence of documented events on a well-monitored slope) provide a negative constraint: the model should not substantially exceed the observed maximum extent.

Step 2: Run an initial simulation with default parameters

Configure the release zone, select the rock shape most representative of the observed block (see section 4.2), and run an initial simulation using the default soil parameters for the dominant terrain type. Use at least 50–100 trajectories per release point for this first pass.

Step 3: Compare modelled vs. observed runout

Extract the simulated deposition point distribution (**Statistics → Nr of Deposited Rocks** or the trajectory endpoints file). Compare the 50th and 95th percentile runout distances against the observed deposition extent.

- **If the simulated 50th percentile runout substantially exceeds observed deposition: the model is over-predicting. Decrease M_E (softer soil → deeper scars) or increase C_d (more drag). Check also whether the rock shape is appropriate.**
- **If the simulated 50th percentile runout substantially falls short of observed deposition: the model is under-predicting. Increase M_E (harder soil → shallower scars) or C_d , or re-evaluate the rock shape and release configuration.**

In practice, the 50th percentile runout distance of the observed deposits is a useful

calibration target for the "typical" trajectory, while the 95th percentile of the simulation should envelop the maximum observed extent but should not greatly exceed it.

Step 4: Compare modelled vs. observed bounce heights

If bounce height data (tree scars, field marks) are available, extract jump height profiles along the slope from the Line Profile tool (**Extras → Profile → Draw Line Profile**). Compare modelled Q50 jump heights at the locations of observed marks against the recorded heights.

- **Jump heights controlled primarily by C_d (drag): high C_d damps bounce; low C_d produces higher rebounds.**
- **Jump heights also controlled by rock shape: equant blocks generally produce more regular bouncing than platy blocks.**
- **If jump heights are consistently too low, reduce C_d ; if consistently too high, increase C_d or switch to a rounder shape.**

Note that jump height and runout cannot always be simultaneously matched with a single parameter set — this indicates a limitation of the model for the specific event, which should be documented.

Step 5: Compare modelled scar dimensions

If scar data are available, compare the modelled scar depth output (available in Statistics Mode: scar depth map) against observed crater depths in the field. The scar depth is primarily controlled by M_E . Field scar depths provide an independent, often under-utilised constraint on M_E that is more direct than runout calibration alone (see Lu et al., 2019).

Step 6: Iterate and document

Adjust one parameter at a time and re-run the simulation. Document all parameter changes and the evidence used to justify each change. If the simulation requires parameters substantially outside the default ranges in Table 4.4, this should be noted in the project documentation as a site-specific finding and the reason should be geologically justified.

Table 4.5: Strategies for model calibration.

Observation	Possible Cause	Adjustment
Runout too long	M_E too high (soil too hard) or C_d too low	Decrease M_E and/or C_d
Runout too short	M_E too low (soil too soft) or C_d too high	Increase M_E and/or C_d

Jump heights too high	C_d too low	Increase C_d
Jump heights too low	C_d too high or rock shape too round	Decrease C_d or use a more angular shape
Scars too deep	M_E too low	Increase M_E
Scars too shallow	M_E too high	Decrease M_E
Poor lateral spread	Wrong rock shape or terrain mismatch	Revise shape or DEM

The model assumes rocks are indestructible.

- If the calibration event involved significant fragmentation of blocks during transport, RAMMS::Rockfall will tend to over-predict runout (since the fragmented pieces are smaller and lose energy faster in reality).

4.9 Forest/Vegetation

Forests are modeled with randomly distributed single trees. The trees are generated randomly according to the area of a given shapefile, a defined tree density (trees/ha), and a Gaussian distribution for the diameter at breast height (DBH) of the individual trees given by a mean DBH and a standard deviation. Each individual tree is modeled as a rigid truncated cone with a DBH from the Gaussian distribution and tree height. The tree height depends on the DBH and follows the following empirical relationship of L. Dorren:

$$H_{Tree} [m] = DBH [cm]^{0.8} \quad (4.19)$$

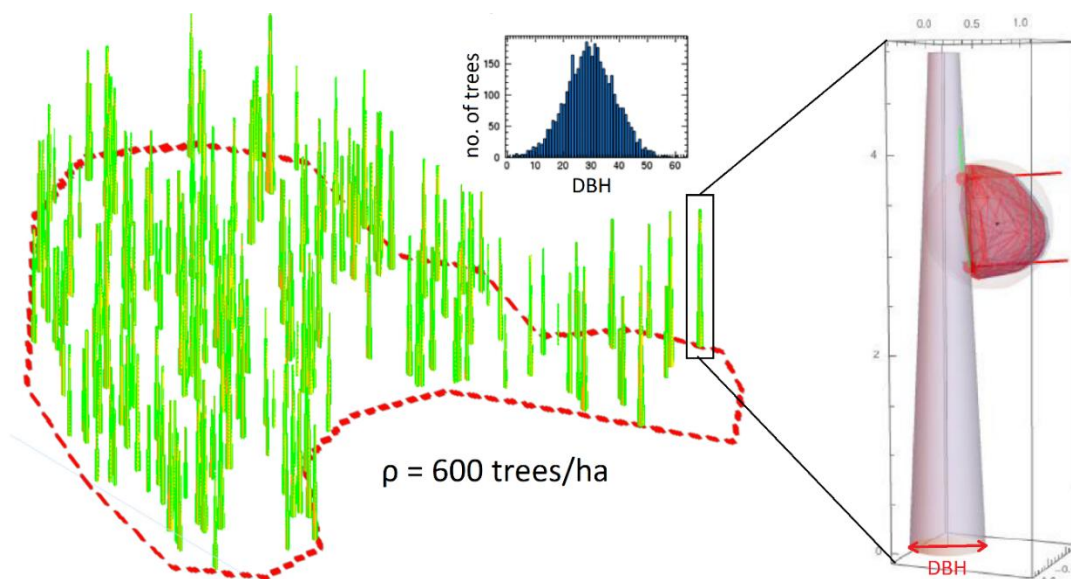


Figure 4-17: Modelled forest in RAMMS:: ROCKFALL with a tree density and a Gaussian distribution of DBH.

RAMMS::Rockfall provides three default forest types with the following parameters:

Table 4.6: Default forest types in RAMMS::Rockfall.

Forest Type	Tree Density [ha ⁻¹]	BHD [cm]	
		μ	σ
Open Forest	200	25	5
Medium Forest	400	28	7
Dense Forest	600	30	9

4.9.1 Energy Dissipation, Tree Contact and Destruction

Trees are modelled as rigid cones. The interaction between tree and rock is therefore an impact between two rigid objects. The impact and rebound physics generally follow the same hard contact and friction principle introduced in chapter 4.7. Additionally, each individual tree is automatically assigned a kinetic energy threshold depending on the DBH (Dorren, 2006):

$$E_{diss,max} [J] = 38.7 \cdot DBH [cm]^{2.31} \quad (4.20)$$

Trees that get hit by rocks with a higher energy than the threshold will be destroyed. As trees are modelled as rigid objects, they can only follow binary states considering tree destruction. This is not problematic for kinetic energies that are a lot higher or lower than the threshold introduced in (4.20). Near the threshold, we can however expect a very complicated transition zone to tree failure, and between full deflection of a rock and punch-through failure. For this reason, a transition-factor ($T_f = 2$) is introduced, which is used to decide if a rock is deflected, and if a tree is destroyed. If the rock energy is between $E_{diss,max}$ and $(T_f \cdot E_{diss,max})$, the tree is destroyed but the rock will still be deflected by the tree. If the rock energy exceeds $(T_f \cdot E_{diss,max})$, the tree will have no influence on the rock (see table below).

Table 4.7: Interaction properties between rock and tree for different rock energies. A transition-factor $T_f = 2.0$ is used.

Rock Energy	Tree destruction	Rock deflection
$E_{Rock} < E_{diss,max}$	No	Yes
$E_{diss,max} < E_{Rock} < T_f \cdot E_{diss,max}$	Yes	Yes
$E_{Rock} > T_f \cdot E_{diss,max}$	Yes	No

4.9.2 Lateral Hits and Scratches

RAMMS::Rockfall calculates the eccentricity of the collision between rock and tree. The collision eccentricity C_{ecc} is calculated as the sinus of the angle between the translational velocity vector of the rock and the vector connecting the center of mass of the rock and the center of mass of the tree, when looking from above. C_{ecc} ranges from 0 to 1.

Because we assume that lateral hits are less severe than direct (frontal) hits, we use a special rule to increase the transition-factor T_f for $C_{ecc} > 0.67$ gradually from 2 to 10. This will prevent trees to be completely destroyed (and thus the rock is still being deflected), as the rock only scratches the tree with a high kinetic energy.

The effectiveness of forest braking in **RAMMS::Rockfall** depends on the likelihood that a rock makes direct contact with a tree stem. For equant blocks with high kinetic energy, impacts with trees are common and well-represented by the model. For platy or elongated blocks, trajectories may be more channelled and blocks may pass through forested areas with fewer direct tree contacts. Lu et al. (2021) and Ringenbach et al. (2025) demonstrate that forest protection efficiency is shape-dependent and can be substantially lower for flat blocks than equant blocks of the same mass. This effect is not fully captured by the current model. For critical assessments in forested terrain involving potentially flat-shaped blocks, the model's estimate of forest braking should be treated as an upper bound.

Important limitation — forest shapefiles do not modify soil parameters

When a forest shapefile is assigned in **RAMMS::Rockfall**, the model generates individual trees within that polygon and computes rock–tree interactions as described above. **However, the soil material parameters (M_E and C_d) within the forest shapefile are NOT automatically modified.** If no soil shapefile is specifically assigned to the forest polygon, the global soil type applies unchanged.

In reality, **forested terrain typically has a rougher surface and a more compressible topsoil layer than open grassland or talus.** This additional dissipation — from root networks, organic litter, and irregular micro-topography — is not captured by the tree-

contact model alone. For dense forests on soft substrates, the model may therefore underestimate total energy dissipation.

Recommended practice:

- **In forested terrain on soft soils (e.g. surface soil, subsoil), consider assigning a dedicated soil category to the forest polygon that reflects the softer, rougher character of forested ground, in addition to the forest parameters.**
- **A combined approach using "Alpine Spruce/Beech Forest" soil type within a forest shapefile provides a more conservative and physically consistent representation.**

4.10 Terrain Model

The **RAMMS::Rockfall** model simulates the trajectories of falling rocks in three-dimensional terrain using a high-resolution digital elevation model. The terrain coordinate system is taken as the simulation frame O . Terrain elevation Z_m is specified for each coordinate pair (X_m, Y_m) , for which four coordinate pairs define the vertices of planes constructing the tessellated terrain surface (Figure 4-18). The planes are flat, while their orientation is different because the Z_m - elevation of each coordinate pair can differ. The distance between coordinates (X_m, Y_m) defines the model terrain resolution and therefore the accuracy with which the terrain morphology is represented. Typically, a resolution between 0.5 m and 5 m is employed for simulations, as this accurately models important terrain features such as gullies and cliffs. The properties of each plane can be varied to consider variable surface properties, such as hardness and roughness. For example, forests are defined to be planes with enhanced drag.

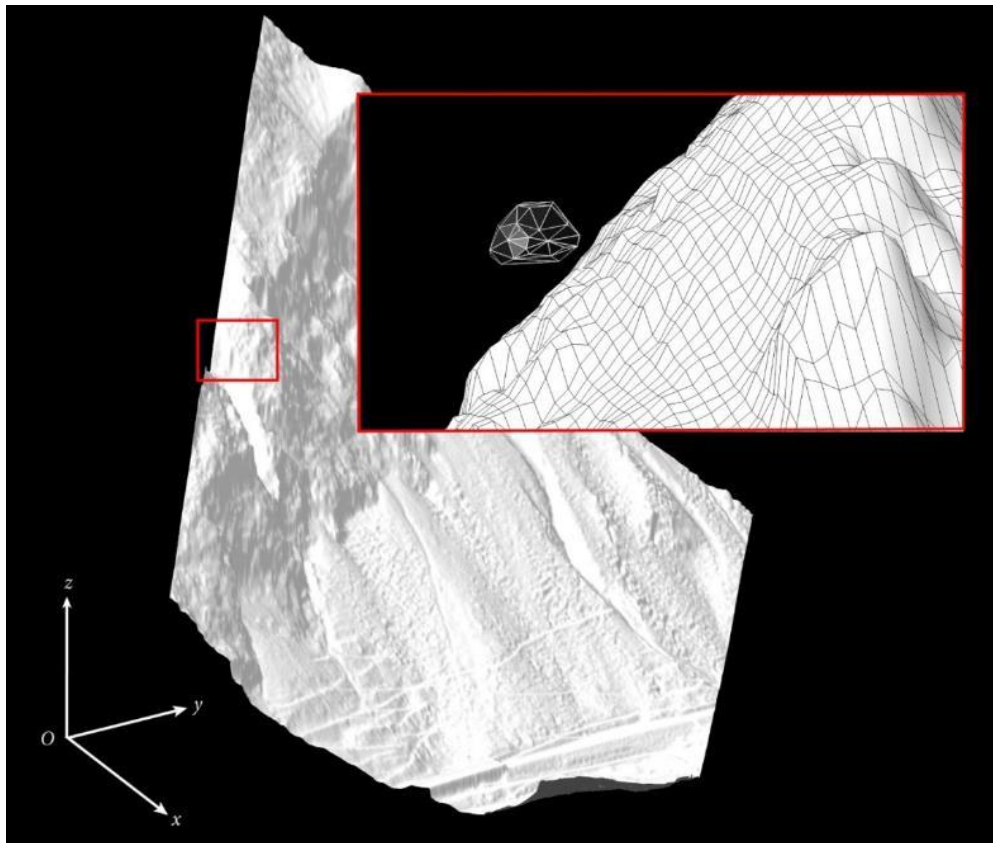


Figure 4-18: High resolution three dimensional terrain model forms simulation frame O in which the four sided planes form the tessellated terrain surface with which the rock-body can come into contact.

DEM resolution

A minimal cell size of 0.5-5m should be used to obtain realistic results. The cell size can be increased in case of long runout distances of > 2 km and scenarios with big block sizes ($>10\text{--}50\text{ m}^3$). If the project perimeter is rather small, corresponding runout distances short ($<50\text{m}$) and the variability of the terrain is high within a few meters, then the cell size of the DEM should be lower, e.g. 1.0 or even 0.5m.

The DEM is the single most important input for RAMMS. A resolution of 0.5–5 m is recommended; coarser DEMs may miss critical terrain features such as cliffs, benches, and gullies that strongly control trajectory paths. Always visually inspect the loaded DEM before running simulations.

5 Setting-Up a Simulation

A complete RAMMS::Rockfall setup requires: a georeferenced DEM, defined release zones with rock shape and size parameters, assigned ground categories with soil strength and drag coefficients, and optionally forest and barrier objects. Always validate simulation results against field observations — runout and energy should match observed deposits.

5.1 Getting Started

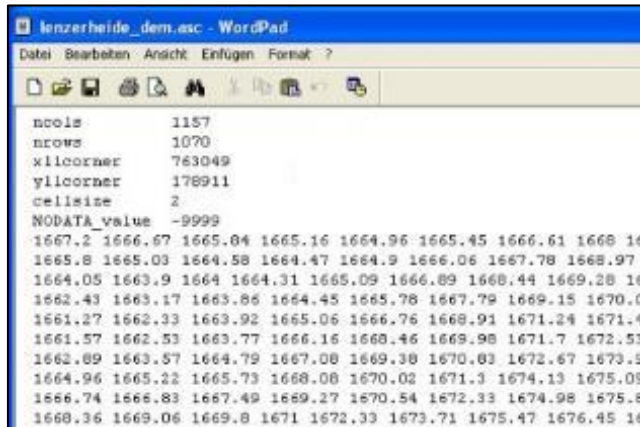
To successfully start a new RAMMS project, a few important preparations are necessary. Topographic input data (DEM in ASCII- or GEOTIFF-format), project boundary coordinates and georeferenced maps or remote sensing imagery should be prepared in advance (.tif format and .tfw-file, maps and imagery are not mandatory, but nice to have). Georeferenced datasets must be in the same **Cartesian coordinate system** (e.g., UTM, Swiss CH1903 LV03, ...) as the DEM. Polar coordinate systems in degree (e.g., WGS84 Longitude Latitude) **are not supported**. For more information about specific national coordinate systems please contact the national topographic agency in your country.

5.1.1 Topographic data - Digital Elevation Model (DEM)

Topographic data is the most important input requirement. How a rock moves (i.e. final runout distance, jump heights, translational and rotational velocities and total energy content of the rock) is strongly influenced by the interaction with the terrain. Therefore, the simulation results depend strongly on the resolution and accuracy of the topographic input data. We recommend a DEM resolution of **0.5-5 m** for meaningful rockfall simulations in complex terrain. However, if such high spatial resolution DEM data is not available, the user must keep in mind that important terrain features may not be correctly represented by the DEM. This can lead to unrealistic simulation results. Before you start a simulation make sure all important terrain features are represented in the input DEM. RAMMS can process the following topographic data:

- **ESRI ASCII grid** (Figure 5-1)
- **GEOTIFF**
- **ASCII XYZ single space data** (Figure 5-2)

The header of an ESRI ASCII grid must contain the information shown in Figure 5-1.



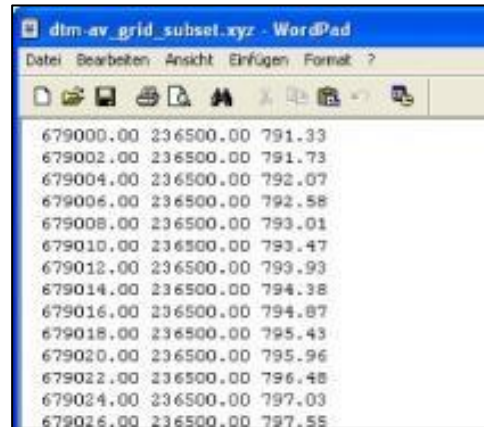
```

lenzerheide_dem.asc
Datei Bearbeiten Ansicht Einfügen Format ?

ncols      1157
nrows      1070
xllcorner   763049
yllcorner   178911
cellsize    2
NODATA_value -9999
1667.2 1666.67 1665.84 1665.16 1664.96 1665.45 1666.61 1668.16
1665.8 1665.03 1664.58 1664.47 1664.9 1666.06 1667.78 1668.97
1664.05 1663.9 1664 1664.31 1665.09 1666.89 1668.44 1669.28 16
1662.43 1663.17 1663.86 1664.45 1665.78 1667.79 1669.15 1670.0
1661.27 1662.33 1663.92 1665.06 1666.76 1668.91 1671.24 1671.4
1661.57 1662.53 1663.77 1666.16 1668.46 1669.98 1671.7 1672.53
1662.89 1663.57 1664.79 1667.08 1669.38 1670.83 1672.67 1673.9
1664.96 1665.22 1665.73 1668.08 1670.02 1671.3 1674.13 1675.09
1666.74 1666.83 1667.49 1669.27 1670.54 1672.33 1674.98 1675.8
1668.36 1669.06 1669.8 1671 1672.33 1673.71 1675.47 1676.45 16

```

Figure 5-1: Example ESRI ASCII grid.



```

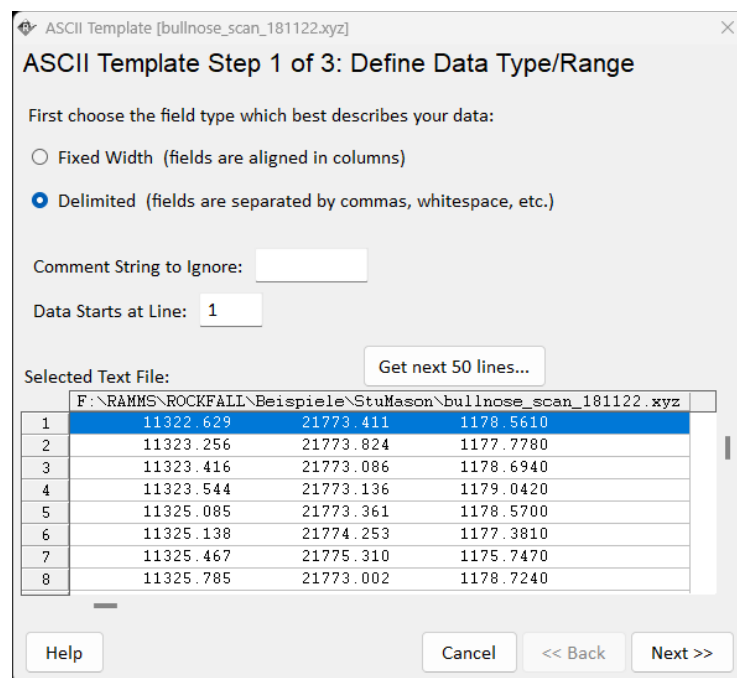
dtm-av_grid_subset.xyz
Datei Bearbeiten Ansicht Einfügen Format ?

679000.00 236500.00 791.33
679002.00 236500.00 791.73
679004.00 236500.00 792.07
679006.00 236500.00 792.58
679008.00 236500.00 793.01
679010.00 236500.00 793.47
679012.00 236500.00 793.93
679014.00 236500.00 794.38
679016.00 236500.00 794.87
679018.00 236500.00 795.43
679020.00 236500.00 795.96
679022.00 236500.00 796.48
679024.00 236500.00 797.03
679026.00 236500.00 797.55

```

Figure 5-2: Example ASCII XYZ single space data.

ASCII XYZ data (regular and irregular) can be converted within RAMMS into an ASCII or GEOTIFF grid. A wizard will guide you through the conversion process, see below. The following interpolation methods are available: *LINEAR* or *INVERSE DISTANCE*. The conversion process is illustrated in Figure 5-3 - Figure 5-5.



ASCII Template [bullnose_scan_181122.xyz]

ASCII Template Step 1 of 3: Define Data Type/Range

First choose the field type which best describes your data:

☐ Fixed Width (fields are aligned in columns)

☒ Delimited (fields are separated by commas, whitespace, etc.)

Comment String to Ignore:

Data Starts at Line:

Selected Text File:

1	11322.629	21773.411	1178.5610
2	11323.256	21773.824	1177.7780
3	11323.416	21773.086	1178.6940
4	11323.544	21773.136	1179.0420
5	11325.085	21773.361	1178.5700
6	11325.138	21774.253	1177.3810
7	11325.467	21775.310	1175.7470
8	11325.785	21773.002	1178.7240

Figure 5-3: Convert XYZ to raster process, step 1 of 3. Choose from which line number to start.

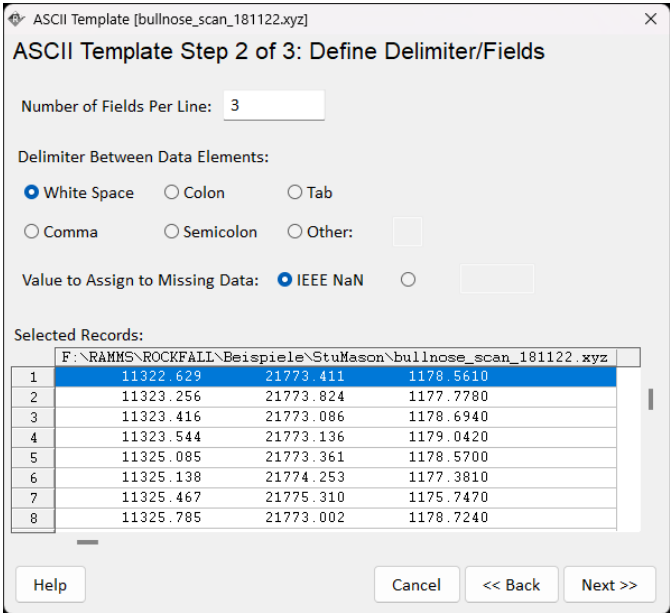


Figure 5-4: Convert XYZ to raster process, step 2 of 3. Choose nr of fields per line and delimiter to use (white space, comma, etc.)

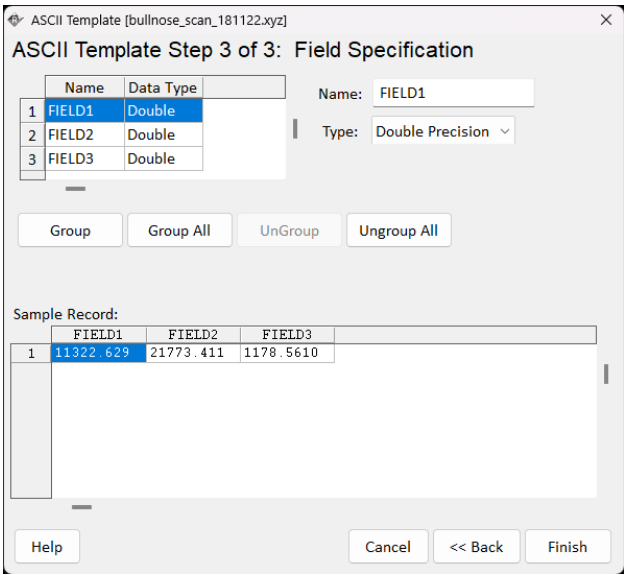


Figure 5-5: Convert XYZ to raster process, step 3 of 3. Specify field types (Integer, float or double)

Click Finish to start the conversion process. RAMMS will suggest the interpolated grid resolution, which the user can change of course:

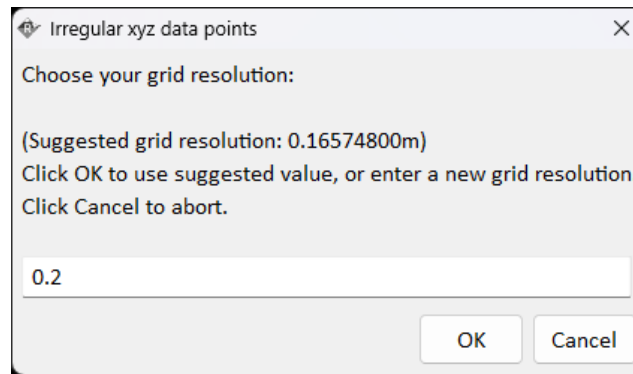


Figure 5-6: Grid resolution suggestion

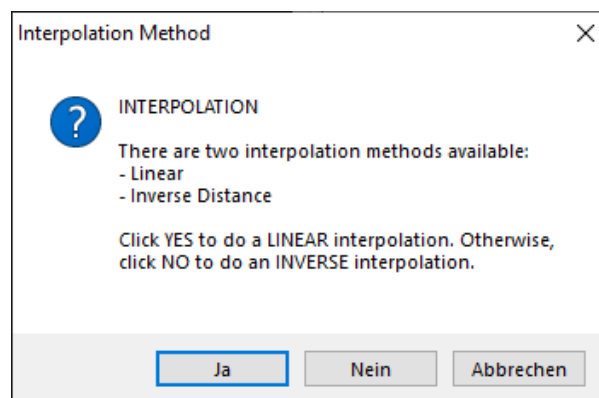


Figure 5-7: Select interpolation method

A tif-file with your raster-conversion will then be created in the same directory as your xyz-file. With this tif-file, you can then create a new project, see chapter 5.20 on page 68.

5.1.2 Project and Scenarios

A project is defined for a region of interest. Within a project, one or more scenarios can be specified and analyzed. For every scenario, a calculation can be executed. A project consists therefore of different scenarios (input files) with different input parameter files (release and friction files). The basic topographic input data is the same for every scenario. If you want to change the topographic input data (e.g., change the DEM resolution or the project boundary coordinates) you must create a new project. Other input parameters (like rock shape, surface information, end time, time step etc.) can be changed for every scenario.

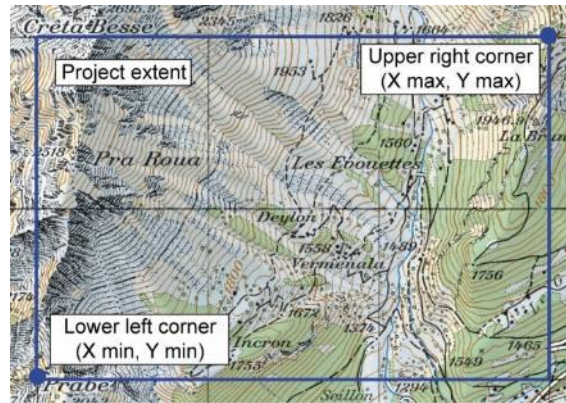


Figure 5-8: The same project extent (area of interest) can be used to calculate different scenarios with different input parameters.

5.1.3 Preferences

To ease the file handling, we recommend setting the preferences prior to start with simulations. The preferences set the path to the working directory and the necessary files such as DEM, maps, and ortho-imagery. If the path to the maps and the imagery files is set correctly in the preferences, RAMMS will automatically open the georeferenced data when you generate a project.

Use **Track** → **Preferences** to open the RAMMS preferences window or click the button



For resetting the general preferences use **Help** → **Advanced...** → **Reset General Preferences**.

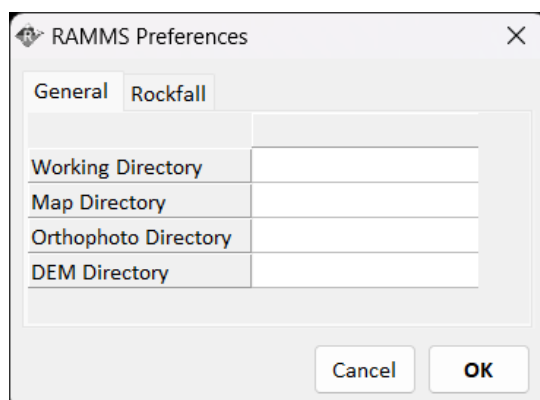


Figure 5-9: General tab of RAMMS preferences.

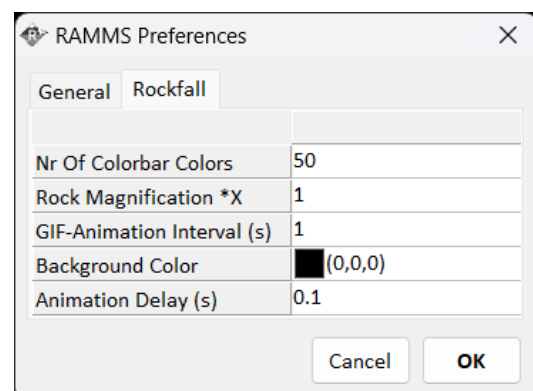


Figure 5-10: Rockfall tab of RAMMS preferences.

General Tab

Setting	Purpose
Working Directory	Set your working directory.
Map Directory	Set the folder where you place your georeferenced digital maps (consists of a .tif file and a corresponding .twf file (world-file)).
Orthophoto Directory	Set the folder where you place your digital georeferenced orthophotos (aerial picture, consists of a .tif file and a corresponding .twf file (world-file)).
DEM Directory	Set the folder where you place the Digital Elevation Models (format ASCII grid)

Rockfall Tab

Setting	Purpose
Nr of Colorbar Colors	Set default number of colorbar colors.
Rock Magnification *X	Set values between 1 and 10 for magnification of the rock size in the visualization.
GIF-Animation Interval [s]	Set interval for GIF animation images in seconds.
Background Color	Set background color.
Animation Delay [s]	Set animation delay to the animation speed.

The following exercise *Working directory* shows how to choose a new working directory. All further settings can be changed in a similar manner. The settings are saved, until they are changed again manually.

Exercise 5.1: Working directory

Choosing the right working directory is very useful and saves a lot of time searching for files and folders.

- Click  (or use **Track** → **Preferences** or **Ctrl+P**) to open the RAMMS preferences window.
- Click into the field *Working directory*. A window pops up where you can choose your new working directory. Click OK in both windows. Do this also for other directories if necessary.

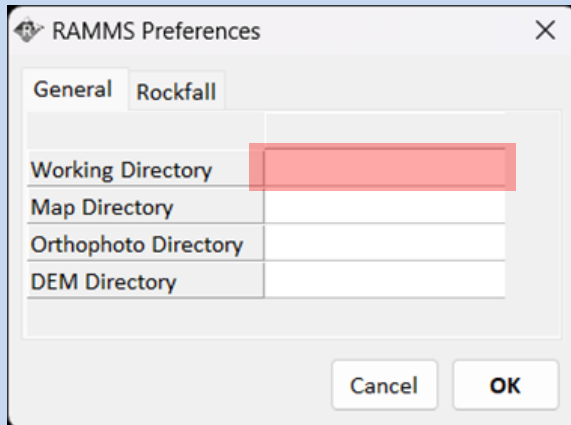


Figure 5-11: RAMMS preferences



Figure 5-12: Browse for the folder.

5.1.1 Additional Preferences

There are many more settings that you can change. Unfortunately, there is no user-friendly widget for this yet. You must change these settings manually (explained below). Use this button in the vertical toolbar on the left or the menu **Help** → **Advanced...** → **Additional Preferences...** → **Edit** to open the Additional Preferences in a text editor, see Figure below.



Figure 5-13: Additional preferences button in the vertical toolbar on the left

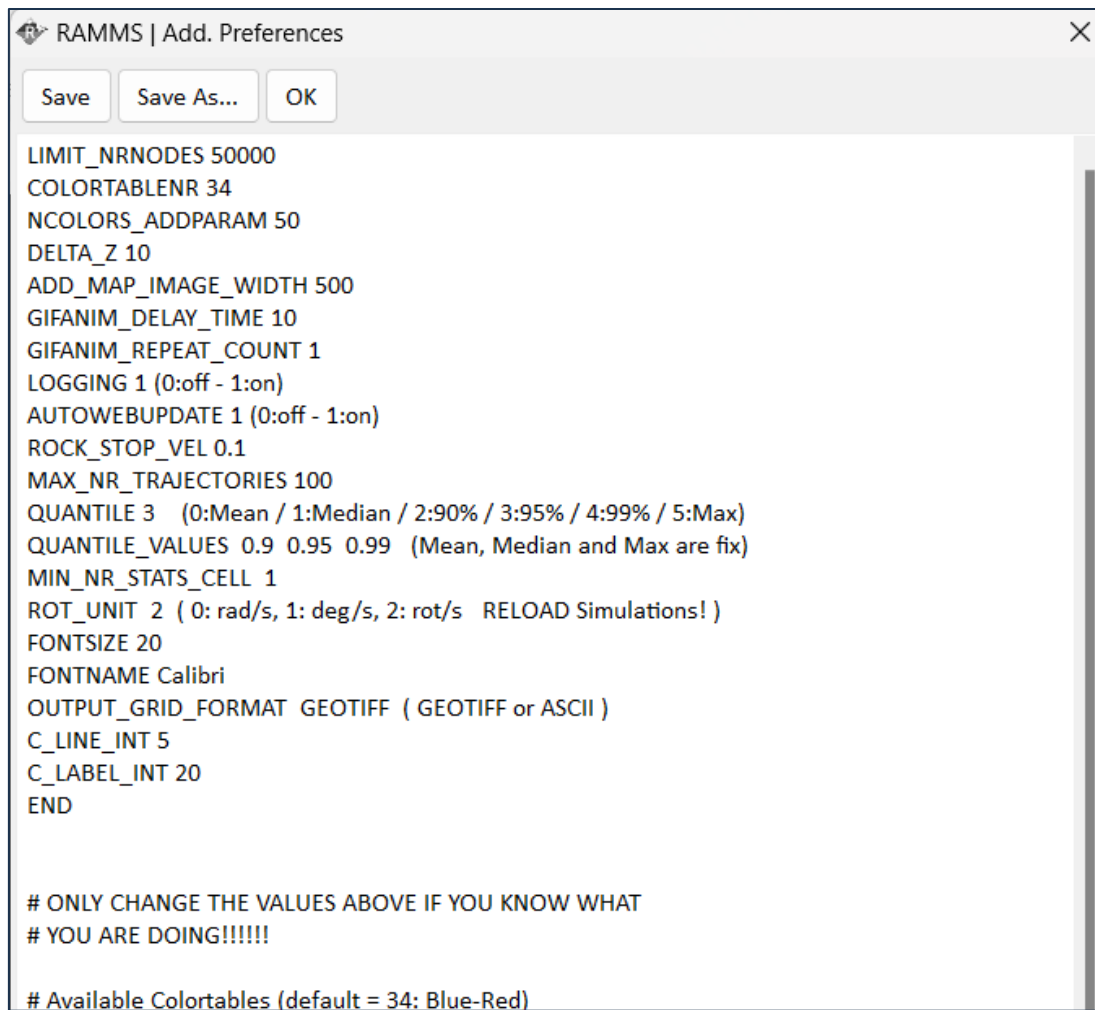


Figure 5-14: Additional preferences file.

Details about above parameters and some more are listed below:

Table 5.1: List of additional preferences

Parameters	Details
LIMIT_NRNODES	The DEM of the topography will be resampled to reduce the number of grid points for visualization purposes. This adjustment will not affect the simulation resolution. Default value is 50'000.
COLORTABLENR	Change the default colortable used in RAMMS. Available colortables are listed below, or can be visualized with <i>Help</i> → <i>Advanced...</i> → <i>ColorTables...</i> → <i>View Available ColorTables</i> . Default value is 34 (Rainbow).

NCOLORS_ADDPARAM	Nr of colors for second colorbar in Output-Mode. Default value is 50.
DELTA_Z	Lines of shapefiles are drawn slightly above the terrain. Default value is 10.0 (m). This is to prevent lines being drawn below the terrain, in case the topography is resamples (see LIMIT_NRNODES above).
ADD_MAP_IMAGE_WIDTH	Width (pixels) of window to select map/ortho images. If filenames are very long, it makes sense to increase this value. Default value is 500.
GIFANIM_DELAY_TIME	GIF-Animation parameter. Set this keyword to an integer giving the delay in hundredths (1/100) of a second after the decoder displays the current image. Default value is 20.
GIFANIM_REPEAT_COUNT	GIF-Animation parameter. Set this keyword to an integer giving the number of times that the decoder should repeat the animation. Set this keyword to zero to repeat an infinite number of times. This keyword is written using the Netscape application extension and may not be recognized by some decoders. Default value is 0.
LOGGING	0: no logging, 1: logging to file. Default is 1.
AUTOWEBUPDATE	0: no AutoWebUpdate, 1: do AutoWebUpdate. If enabled, RAMMS checks online for updates. Default value is 1.
ROCK_STOP_VEL	Stopping velocity of rocks. RAMMS uses this stopping velocity to calculate the min. kinetic energy for each rock. Default value is 0.1 m/s.
MAX_NR_TRAJECTORIES	Reading trajectories in Trajectory-Mode can use a lot of memory. If the user wants to read more trajectories

	than this threshold, RAMMS sends a warning to the user. Default value is 100.
QUANTILE	Default quantile visualization in Statistics-Mode is 3 (0:Mean / 1:Median / 2:90% / 3:95% / 4:99% / 5:Max)
QUANTILE_VALUES	Define three quantile values, default values are 0.9 0.95 0.99 (Mean, Median and Max are given)
MIN_NR_STATS_CELL	Users can specify e.g. a value of 5, meaning that statistics is only calculated for grid cell values containing at least 5 trajectories. Default value is 1.
ROT_UNIT	Definition of rotation unit (0: rad/s, 1: deg/s, 2: rot/s). After changing this parameter, users must RELOAD simulations. , Default value is 2.
FONTSIZE	Change font size of GUI. Default value is 20.
FONTNAME	Change font name of GUI. Default font name is <i>Calibri</i> .
OUTPUT_GRID_FORMAT	GEOTIFF or ASCII
C_LINE_INT	Contour plot. Interval of contour lines in (m). Default value is 20m.
C_LABEL_INT	Contour plot. Interval of contour labels in (m). Default value is 100m.
RELP_SYM_NR	Symbol of visualized release point when defining the random distribution of release points with Set Release , see section 0. Default value is 1. Possible symbols are: • 1: Plus sign (+)

	• 2: Asterisk (*) • 3: Period (.) • 4: Diamond • 5: Triangle • 6: Square • 7: X
RELP_SYM_SIZE	Size of symbol from above. Default value is 1.
RELP_SYM_THICK	Thickness of symbol from above. Default value is 1.
RDP_EPSILON	Tolerance (in meters) used by the Ramer–Douglas–Peucker line/polygon simplification: larger values simplify more (fewer vertices), smaller values keep the original geometry more closely. Default = 0.1m.
PLANE_TOL	Geometric tolerance used when testing whether a point lies on (or very near) an obstacle/terrain facet plane: larger values accept more “near-plane” hits , smaller values require a more exact intersection . Default = 0.01m.
PROFILE_XSIZE	X-size of profile plot window. Default = 900 pixels.
PROFILE_YSIZE	Y-size of profile plot window. Default = 600 pixels.

5.2 Creating a new project

Creating a new project is explained in chapter 3.2 on page 19.

The following files (Table 5.2) will be created in the project folder.

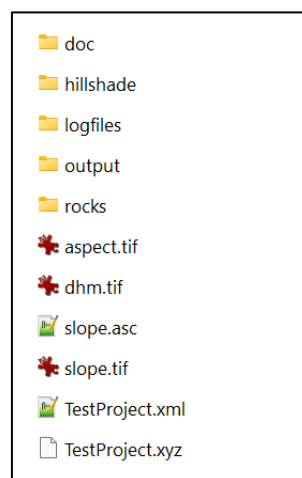


Figure 5-15: Files and directories created with a new RAMMS::Rockfall project.

Table 5.2: Listing of files and directories created with a new RAMMS::Rockfall project.

File / Folder	Purpose
doc (folder)	Folder containing input and output log files
hillshade (folder)	This folder contains a hillshade image of your project region
logfiles (folder)	Project creation and calculation log files
output (folder)	Folder containing calculated scenarios
rocks (folder)	Folder to save rock files (.pts)
aspect.tif	Aspect raster tif-file
dhm.tif	GEOTIFF raster file with altitude values
slope.asc	Calculated slope angles of DEM
slope.tif	Calculated slope angles of DEM
<ProjectName>.xml	Input file
<ProjectName>.xyz	Topographic data used in RAMMS

5.3 Working with the interface

Once the project is created, there are several useful tools which can be helpful when working with RAMMS. They are explained in the exercises below.

5.3.1 Moving, resizing, rotating, viewing

! Hold **Shift** while dragging with the mouse to rotate the topography directly, without manually switching to the Rotate tool. This makes 3D navigation faster, smoother, and more intuitive.

If you need to rotate the model around a fixed axis, see exercise below.

Rotating the model around fixed axis

After activating the rotation button , the model can be rotated along the rotation axis', by moving the cursor directly on one of the axis until the cursor changes from  to . Otherwise, a freehand rotation in any direction is possible.

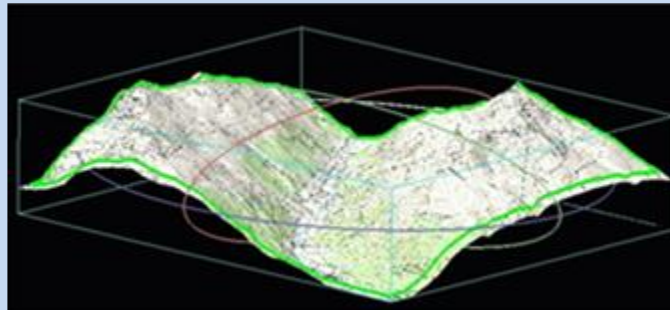


Figure 5-16: Active project with rotation axes.

How to switch between 2D and 3D mode

Click  to switch from 3D to 2D view. This button then changes to  and by clicking again, you will return to 3D view.

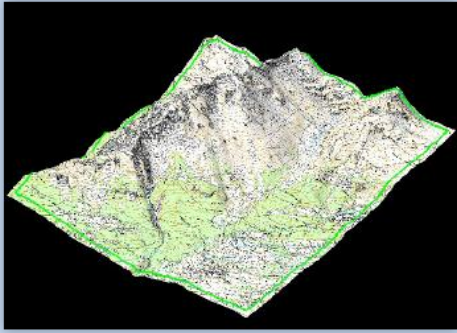


Figure 5-17: 3D view of example model.

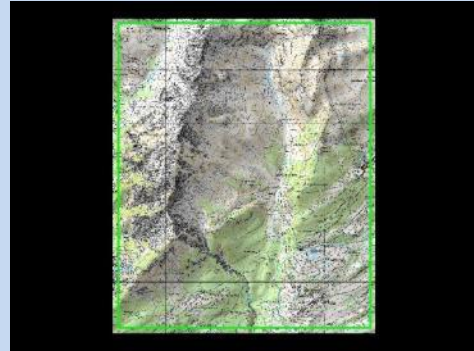


Figure 5-18: 2D view of example model.

In 2D mode you have all possibilities that work for the 3D mode. It works for input files as well as for simulations. **For the following functions of RAMMS it is necessary to switch from 3D to 2D view:**

INPUT:Draw New Release Points Draw New Release Line Draw New Polygon Shapefile Edit Forest Parameters Edit Soil Parameters Release On-Off **OUTPUT:**Draw Line Profile 

5.3.2 Colorbar

As soon as a parameter is shown in the project, the colorbar appears on the right side of the main window. It can be turned on and off by clicking on . The colorbar can be moved anywhere in the screen (and can get lost). Use **Edit** → **Get Colorbar** to find a lost colorbar.

Editing the colorbar

Changing the minimum and maximum values of the colorbar as well as changing the number of colors used is done in the panel **ROCKFALL** (right of the map window) in the *Display* section at the top.

- Simply type a new value into the respective field and hit the **return key** on the keyboard. The display will be refreshed.
- To view the underlying topography or image, you can change the **transparency**.

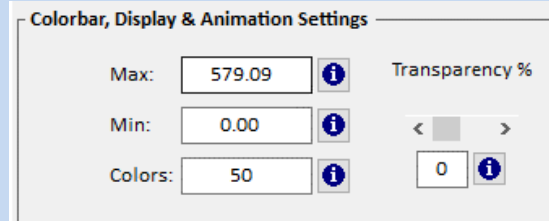


Figure 5-19: Colorbar and Display Options.

- Open the editing window by choosing **Edit → Colorbar Properties**.
- To change the colorbar properties simply click into the field you want to change, then click **OK**.

➔ Using **Edit → Colorbar White Color** the text-color of the colorbar can be changed to white. This can be useful when changing the background color of your project to black or white **Track → Preferences → Rockfall Tab → Background Color**.

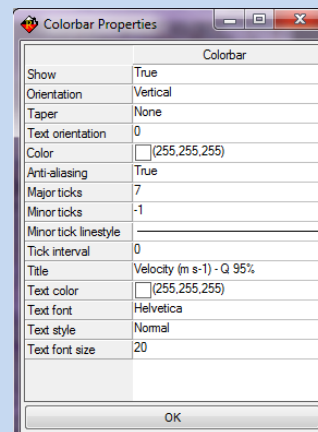


Figure 5-20: The Colorbar Properties window.

5.3.3 Changing maps and remote sensing imagery

It is possible to change the map or imagery of a project anytime. Be aware, that the corresponding *.tfw-file (world-file) must be in the same folder as the actual map (.tif). If this is not the case, the map will not be found!

How to add or change maps

a. Add or change a map:

- Go to **Extras → Map... → Add/Change Map** or click .
- If more than one map is found, the following window pops up, listing the maps found:

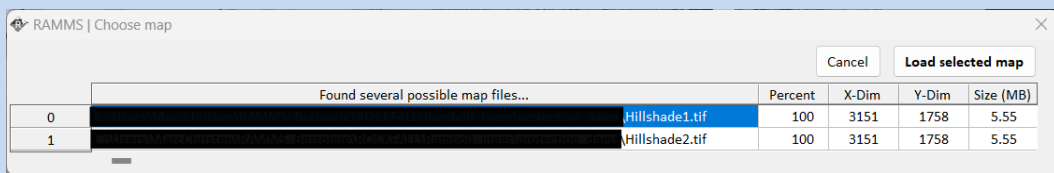


Figure 5-21: Window to choose map image.

- Information on the image dimensions (x-Dim and y-Dim, pixel) and size (in MB) are provided and might be a selection criterion.
- Select the map you wish to add and click **Load selected map**.

b. Map not found:

- If the question "No map found, continue search?" appears, you either don't have an appropriate map, the map-folder directory is set wrong, or the map is saved in a different folder. In the second case click **Yes** and choose the correct folder. A window pops up to browse for the correct map location and file.
- Or click **No** to cancel search.

c. Change remote sensing imagery:

- Go to **Extras → Image... → Add/Change Image** or click .

5.3.4 Hillshade visualization

When creating a new project, a hillshade GeoTIFF image is automatically created by RAMMS, and saved in the *hillshade* folder. If you open an old project, you can still create a hillshade image by using **Extras → Create Hillshade Image**. RAMMS follows the instructions from ArcGIS at

<https://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-analyst-toolbox/how-hillshade-works.htm>

to calculate the hillshade representation of your DEM, see Figure 5-22 and Figure 5-23.

Go to **Extras → Image... → Add/Change Image** or click  to load a newly generated hillshade image into the project.



Figure 5-22 DEM surface visualization (with shadows) after creating a new project in RAMMS.

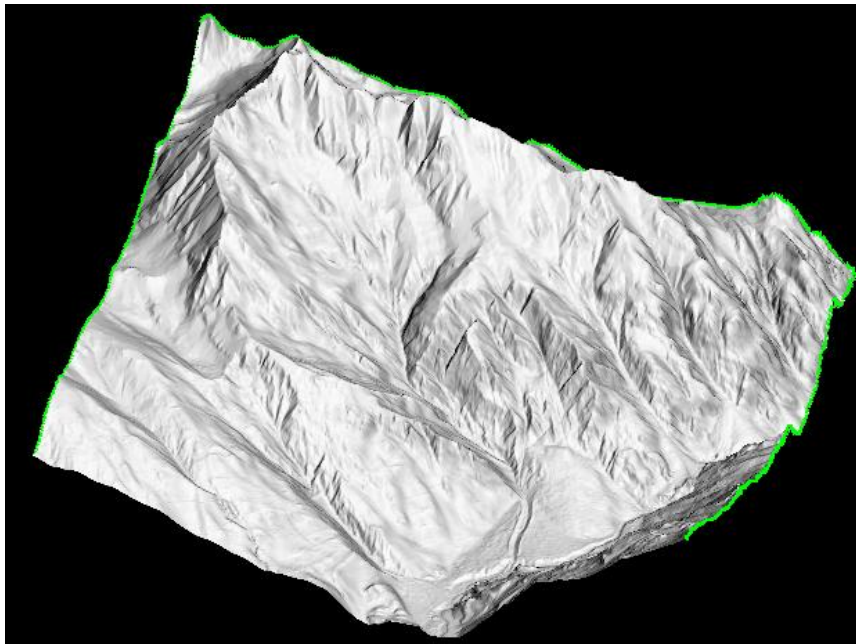


Figure 5-23 Visualization after creating and adding the hillshade image to RAMMS.

5.3.5 Show Slope Angles or Contour Lines

  With these two buttons in the horizontal toolbar, slope angles and contour lines can be visualized (Figure 5-24).

-  **Slope angle**
-  **Contour lines**

By again clicking on the same symbol, the visualization is removed.

Line and label intervals of the contour plot can be set in the Additional Preferences, see section 5.1.1 on page 64.

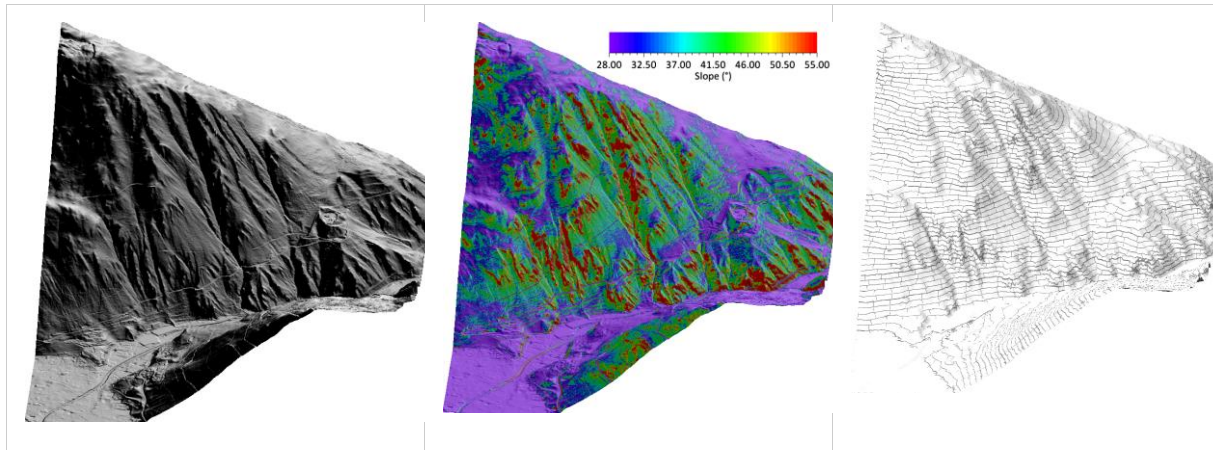


Figure 5-24: Left: Hillshade image, Middle: slope angle Right: contour lines

5.3.6 How to save input files and program settings

Once a project is created, it is saved under the name and location you entered in the RAMMS Project Wizard (Section 0). The input file format is xml. The second situation, in which the input file is saved automatically, is when a simulation is started. The saved input file has the same basename as the created output file.

How to save input files and program settings manually

a. Input file:

- In case you want to save the input file manually before running a simulation, go to **Track** → **Save**. This is helpful, when for example a release line was loaded but you wish to close the project before doing the simulation.
- If you wish to save a copy of your file under a new name, go to **Track** → **Save Copy As** or click .
- A window pops up to choose an old file which should be overwritten or to type in a new name, then click **Save**.
- Continue working on the original file, not the just saved one.

b. Position settings

- If you have moved and/or rotated your project for a better view, you can save this position by going on **Extras** → **Save Active Position**. There is also a button in the horizontal toolbar for this operation → .
- You can now get back to this position anytime by choosing **Extras** → **Reload Position**.

How to open an input file

Close any active project file .

- Go to **Track** → **Open** → **Input File** or click .
- A window opens to browse for a rockfall input file (.xml).
- Click **Open** after the file name was selected.
- The project will be opened.
- You can access recent input files by choosing **Track** → **Recent...**

How to load an optional shapefile

- To load a shapefile, go to **GIS** → **Import Shapefile** or click .
- A window opens to browse for a shapefile (.shp).
- Click **Open** after the file was selected.

How to open an output file/rockfall simulation

Close any active project file .

How to open a scenario in Statistics-Mode:

- Go to **Track** → **Open...** → **Rockfall Scenario** or click .
- Scenarios are located in the *output* folder of your project directory. Choose a scenario folder and click **OK**.
- If you want to open several scenarios (from the same project) together, click **Track** → **Open...** → **Rockfall Scenario (Filter/Multi)**, and then choose more scenarios, or use a filter to open only specific output results (e.g. with the same rock-name).

How to open trajectories from a scenario in Trajectory-Mode:

- Go to **Track** → **Open...** → **Rockfall Trajectories (Ctrl+T)** or click .
- A window opens to browse for rockfall simulation files (.rts). Click **OK**.
- The simulation(s) will then be opened.

- If you want to open trajectories from different scenarios (from the same project) together, click **Track** → **Open...** → **Rockfall Trajectories (Filter/Multi) (Ctrl+F)**, and then choose more trajectories from a different scenario folder, and/or use a filter to open only specific trajectories (e.g. with the same rock-name).

Or use the recent menu to open recently opened input files or scenarios (**Track** → **Recent...**).

5.3.7 Activity-Log

The **Activity Log** records the most important actions you take in **RAMMS::Rockfall** so you can audit your work, retrace steps, and find files quickly. It's lightweight, human-readable, and appends a single line per action.

What gets logged

Each entry is a semicolon-separated line:

timestamp ; action ; project ; scenario ; file ; path

- **Timestamp:** Local time in YYYY-MM-DD HH:MM:SS.
- **Action:**
 - **OPEN_INPUT:** Open input file
 - **OPEN_STAT:** Open scenario in Statistic-Mode
 - **OPEN_TRAJ:** Open trajectories in Trajectory-Mode
 - **NEW_PROJECT:** Create a new project
 - **RUN_SCENARIO:** Running simulations for a scenario

- **Project:** Your project name.
- **Scenario:** Scenario name.
- **File:** Input filename, or nr of trajectories opened in Trajectory-Mode.
- **Path:** Directory/path of action.

New entries are written **at the top** of the file (newest-first) for quick scanning.

Why this is useful

- **Reproducibility & audits**
- **See exactly what you opened or ran and when, tied to the project/scenario and file location.**
- **Faster “where did I save that?”**
- **The file + path split makes it easy to search for a name and copy the folder path.**

- **Minimal overhead**
- **Plain text, append-only, no database. Works offline and with version control.**

Viewing and filtering

- **Show all recent activity:**
- **Track → Activity Log... → Show All.** RAMMS displays a neatly aligned text view (monospaced) of the CSV.
- **Show this year's activity:**
- **Track → Activity Log... → Show this Year.** RAMMS displays a neatly aligned text view for all activity from this year.
- **Quick filters by action:**
- **Track → Activity Log... → Filter by Action.** Choose one action (e.g., Open_Input) to show only matching lines. Typical filters are one of the actions from above:
 - **OPEN_INPUT:** what inputs have I opened?
 - **OPEN_STAT:** which results did I inspect?
 - **OPEN_TRAJ:** which trajectories did I inspect more closely?
 - **RUN_SCENARIO:** when did I run this scenario?
 - **NEW_PROJECT:** when did I create this project?

Tip: Because each field is plain text, you can also open the CSV in any editor or spreadsheet and filter there.

Good practices

- **Use clear project/scenario names.** They become searchable tags in the log.
- **Keep filenames meaningful.** The file column is the quick visual cue; the path is the precise location.
- **Archive per year.** The log rotates annually (ramms_activity_YYYY.csv) so files stay rather small and snappy.

5.3.8 About RAMMS

Some information about the RAMMS installation on your computer is found here:
Help → About RAMMS.



Figure 5-25: About RAMMS::Rockfall

5.4 Shapefiles

Shapefiles are used for all spatially variable input data, such as the definition of rockfall release zones (see section 5.5), definition of areas with specific terrain material (see section 5.6), or the definition of forested areas (see section 5.7). The workflow is always the same. First, the user creates or imports shapefiles and then assigns terrain parameters, forest or release zones. All shapefiles of a project are shown in the file tree in the right panel under the **Files** tab (Figure 5-26).

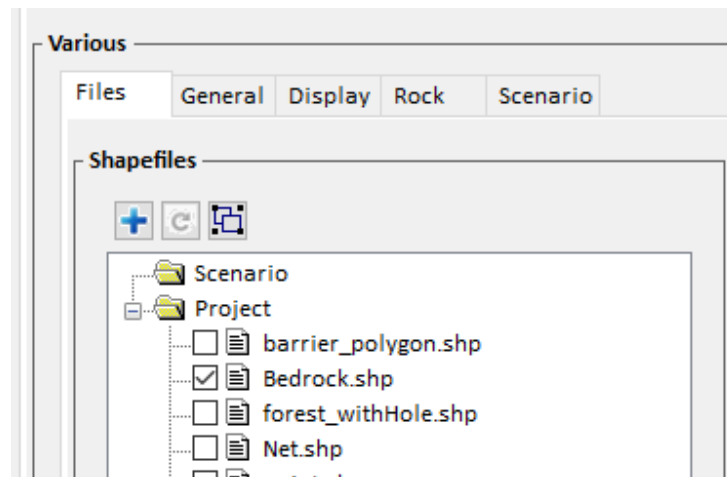


Figure 5-26: File tree with all shapefiles of a project.

The checkbox to the left of a shapefile in the file tree can be used to activate or deactivate a specific shapefile. This will hide the shapefile visualization from the view. The shapefile will not be considered during a simulation, meaning that if a deactivated shapefile has an assigned ground category, forest or release property, this information is ignored. Shapefiles can only be drawn in 2D mode.

5.4.1 Drawing Shapefiles

Create Point Shapefile

Click  or use **Input → Point → Draw New Release Point(s)**, move the cursor to the desired position and click with the left mouse button to create as many points as you want. Finish the process with the right mouse button and enter a name for your point shapefile.

Alternatively, you can create a point shapefile by entering its X/Y coordinates. Go to **Input → Point → Enter Point Coordinates (X/Y)** and enter the coordinates with a space delimiter in the reference system of the DEM. Click **OK** and optionally define additional points for the same shapefile.

Create Line Shapefile

Draw a new line shapefile by clicking  or use **Input → Line/Area → Draw New Release Line(s)**. Draw the line by clicking points with your left mouse button. If you want to delete the last drawn point of the line, click the middle mouse button. Finish the line by clicking on your right mouse button. You can then optionally choose to define additional lines within the same shapefile. Enter a name for the line shapefile.

Create Polygon Shapefile

Draw a new polygon shapefile by clicking  or use **Input → Line/Area → Draw New Polygon Shapefile**. Draw the polygon in clockwise direction with left mouse clicks. If you want to delete the last drawn point of the polygon, click the middle mouse button. Finish and automatically close the polygon with a right-click. You can then optionally choose to define additional polygons within the same shapefile. It is possible to define holes within polygons. For this, draw the outer polygon in clockwise direction, then in the dialog **Add more polygon areas?** Click **Yes** and draw the hole with left mouse clicks in **counter-clockwise** direction. Confirm with a right mouse click and confirm that the polygon is a hole. Enter a name for the release shapefile.

5.4.2 Import Shapefiles

If you would like to import shapefiles from other projects or from GIS, there are two options.

- To import a single shapefile, click  in the left toolbar or **choose GIS → Import Shapefile**, select the shapefile in the file browser and click Open. The selected shapefile is then added to the file tree in the right panel. Please make sure that the shapefile is in the same reference system as the DEM of the project (Figure 5-26). Navigate to the desired directory, select it, and click OK. All shapefiles inside the selected folder are then added to the file tree in the right panel. Please make sure that the shapefiles are in the same reference system as the DEM of the project.

5.4.3 Calculation Domain

This feature is designed to define a smaller calculation domain, significantly improving computation speed. To specify a polygon shapefile as a calculation domain, right-click it in the file tree in the right panel and select '*Set Calculation Domain*'. The line color of the selected shapefile will then change to **green**, indicating that this shapefile is a **calculation domain**.

Reverting a shapefile to a **normal** shapefile, choose '*Remove Calculation Domain*'. The line color will then switch back to red.

Once a calculation domain is specified, assigning release points within a shapefile will only take polygons within the calculation domain area into account.

Shapefiles define spatially variable input data: release areas, ground categories and forest zones. All shapefiles must be in the same coordinate system as the DEM. Create shapefiles in a GIS before importing — RAMMS does not include a full shapefile editor.

5.5 Assign Release Zones

A rockfall starting zone can be specified by setting a release point, drawing release line(s) (containing many release points) or defining release area(s) (polygon). The definition and localization of a rockfall starting zone have a strong impact on the results of RAMMS simulations. Therefore, we recommend using reference information such as photography, GPS measurements or field maps to define release points, release lines and release areas. This should be done by experts with experience concerning the topographic, geological, and meteorological situation of the investigation area.

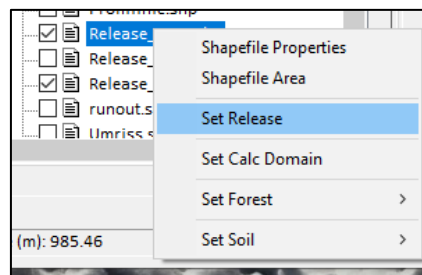


Figure 5-27: Setting a shapefile as a release.

To flag a shapefile as a release shapefile, right-click the specific shapefile (point, line or polygon) in the file tree and select **Set Release** (or select the *Release On-Off* tool  in the top toolbar and click into a polygon).

You can flag as many shapefiles as you want as release zones simultaneously. Release shapefiles are always marked with a **blue color**. Depending on the shapefile type, you need to enter additional information, see below. To visualize randomly distributed release points in release polygons, it makes sense to zoom closely to your release polygon.

5.5.1 Release Point

You do not need to provide more information. A dialog opens that shows the number of points within the shapefile. Click **OK** to confirm. See Exercise 5.2a below for more details.

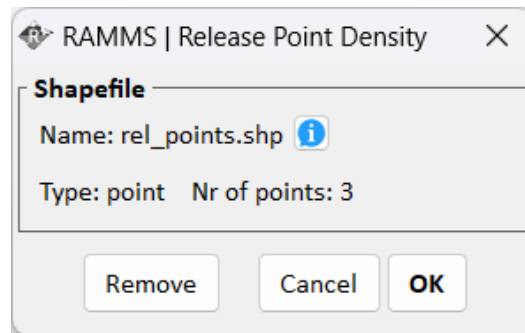


Figure 5-28: Release Point – Set Release

5.5.2 Release Line

Enter the amount of release points that will be evenly distributed along the defined line (don't forget to hit **ENTER!!**) and click **OK**. See Exercise 5.2b below for more details.

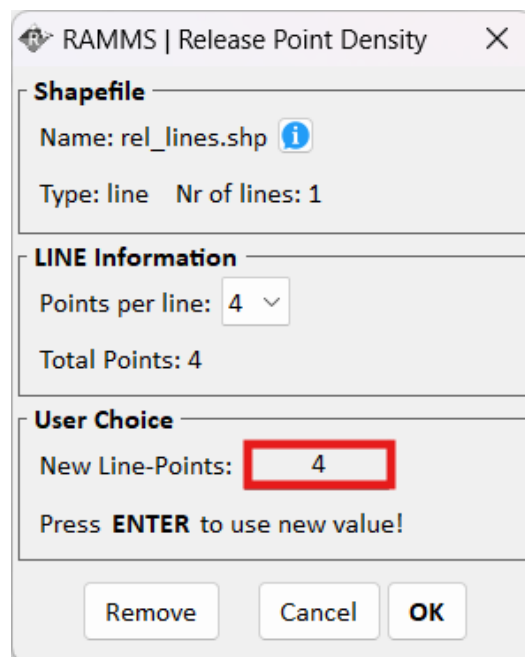


Figure 5-29: Release Line - Set Release

5.5.3 Release Area

A dialog opens, where a **Release Point Density** needs to be defined.

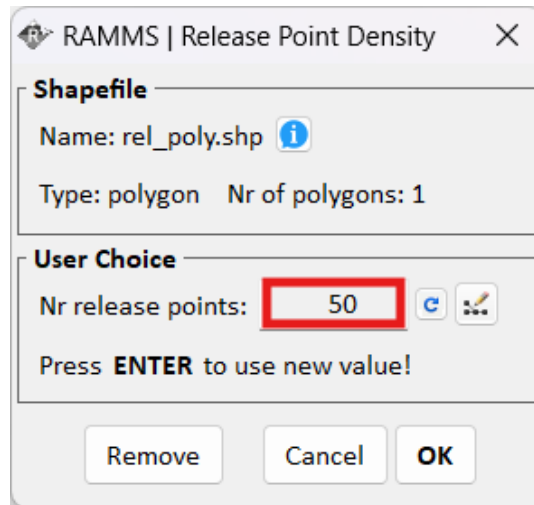


Figure 5-30: Release Point Density Dialog for Polygon Shapefiles.

Enter the amount of release points that will be randomly distributed within all the polygons of your release shapefile (or only in one selected polygon, depending on how you selected this dialog; either by right-clicking on a shapefile in the file tree, or by using the Release On/Off button  in the horizontal toolbar, and selecting one of the polygons). Don't forget to hit **ENTER** after you entered the number of release points.

5.5.4 Removing Release Zones

To remove release zones, there are two different ways:

- Deactivate the shapefile by removing the checkmark left of it in the file tree. Be aware that this deactivates all properties of the shapefile. Meaning, if you have also assigned a ground type to a release polygon, the ground type information will be ignored as well.  release_line.shp
- Right-click on the shapefile in the file tree, select Set Release and then click on Remove (see Figure above).

Exercise 5.2a: How to define a release point

- Switch to 2D mode by clicking .
- Activate the project by clicking on it once.
- Click  to start drawing a point shapefile.

- Left-click into the project where you want to define your rockfall release point. You can draw as many points as you want. If you would like to delete the last point, click the *middle* mouse button.
- Finish by clicking with the right mouse button and enter a name for the shapefile. You will see red plus signs at the location of your release points.



Figure 5-31: Defining 4 release points.

- Color, thickness and point symbol of your release points can be changed by right-clicking the shapefile in the file tree and selecting **Shapefile Properties**.

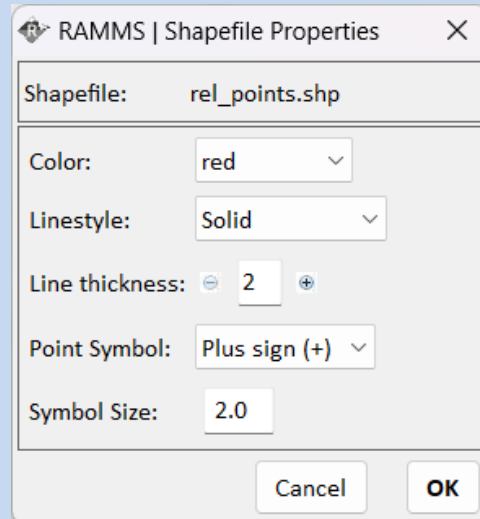


Figure 5-32: Shapefile Properties of release points

- To flag the release point shapefile as a release file, right-click the shapefile in the file tree and select **Set as Release** and then **OK**.
- The point(s) should then change the color from red to blue.

Exercise 5.2b: How to create a new release line

- Switch to 2D mode by clicking .
- Activate the project by clicking on it once.
- Click  to start drawing a new line shapefile.
- Click into the project where you want to start drawing the outline of the release line.
- Continue drawing the release line by moving the cursor and clicking *the left mouse button*. If you would like to delete one step of the drawing, click the *middle mouse button*.
- Finish by clicking the **right** mouse button. Optionally draw additional release lines in the same shapefile. Enter a name for the shapefile after drawing the last line.

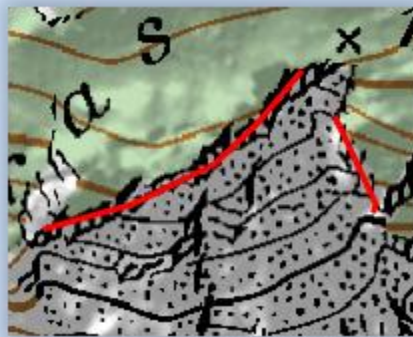


Figure 5-33: Project with emerging release lines.

- Right-click the shapefile in the file tree and select **Set as Release**.
- Enter the amount of release points that will be evenly distributed along the defined line(s) and click OK. The line should then turn from red to blue.

Exercise 5.2c: How to create a new release polygon

- Switch to 2D mode by clicking .
- Activate the project by clicking on it once.
- Click  to start drawing a new polygon shapefile.
- Click into the project where you want to start drawing the outline of the release polygon.
- Continue drawing the release polygon by moving the cursor and clicking *the left mouse button*. If you would like to delete one step of the drawing, click the *middle mouse button*.

- To end the release polygon, click the **right mouse button**. Optionally, draw additional release polygons in the same shapefile. Enter a name for the shapefile after drawing the last polygon.



Figure 5-34: Example of release polygon area.

- Right-click the shapefile in the file tree and select **Set as Release**.
- Enter the amount of release points that will be randomly distributed within the defined polygon and click OK. The polygon should then turn from red to blue.

Exercise 5.2d: How to load an existing release point/line/area

- Import a **single** shapefile by clicking  in the left toolbar or import a folder with **multiple** shapefiles by clicking  above the file tree.
- Uncheck all checked (and visualized) shapefiles by clicking the *Uncheck All* button .

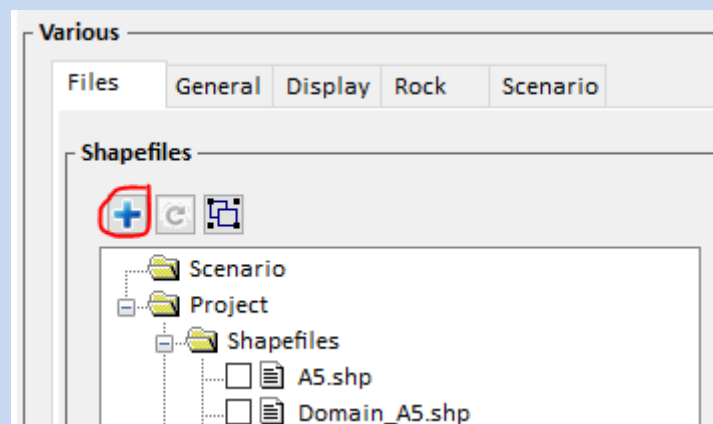


Figure 5-35: Import all shapefiles from a folder

- Right-click on the imported shapefiles in the file tree and select **Set Release**
- Depending on the shapefile type, define the amount of release points along a line shapefile or the release point density within a polygon shapefile.

Release zones can be defined as single points, lines, or polygon areas. For hazard studies, polygon release zones covering the full potential source area give the most complete picture of runout variability.

5.6 Assign Ground Categories

If you want to use more than just one global soil/ground category, you must define polygon areas and assign soil types to them. You can either draw new polygon shapefiles directly in RAMMS (see section 0) or import already existing shapefiles from previous projects or from GIS (see section 5.4.2). Choose appropriate filenames for the different shapefiles while generating them so there is no confusion which shapefile belongs to which terrain type. To assign a soil category to a polygon shapefile you can either:

- **Select the Edit Soil Parameters tool**  in the top toolbar and click into the polygon. With this tool, you can assign different ground categories to polygons of the same shapefile. Only the selected polygon will be assigned to the ground category.
- **Right-click on the shapefile in the file tree** in the right panel and select **Set Soil**. If a shapefile consists of several polygons, all polygons will be assigned to the chosen soil type.

This shows a list where you can either choose a default soil type or enter custom values for M_E and C_d by choosing Edit Soil.

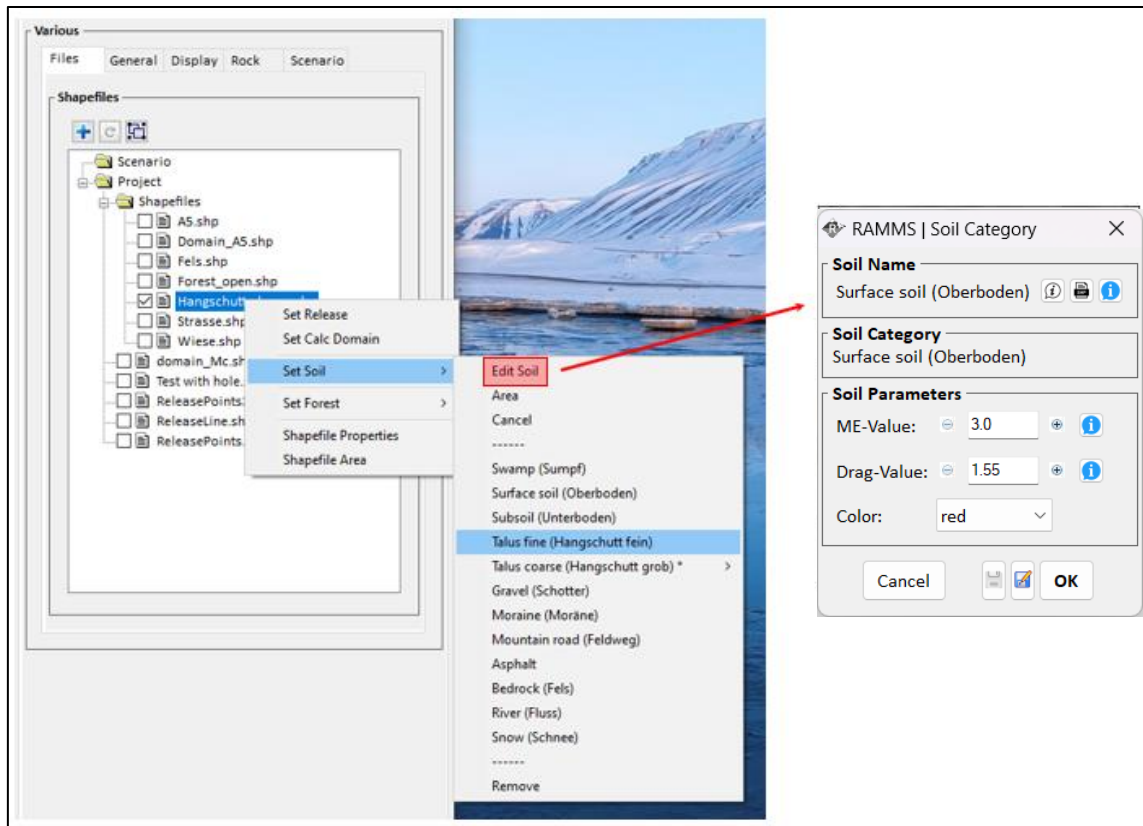


Figure 5-36: Assigning a soil type to a polygon shapefile from the file tree (left) and dialog to enter custom values for ME and Cd (right).

Each soil/ground category defines the parameters of the soil compressibility as well as a ground-drag value. The ground-drag value accounts for the viscoplastic drag due to terrain deformation during ground-contact and -scarring. The two input parameters are explained in more detail in chapters 4.8.1 and 0. The default ground parameters provided by RAMMS are described in Section 0.

Please use these parameters with the awareness that they are currently based on case studies and real-scale experiments. It remains an ongoing research task to reassure these parameters rigorously.

The soil compressibility and drag coefficients should be defined for every terrain material shapefile. The list below gives an overview on some possible terrain materials. You can choose between the categories:

Surface Soil, Subsoil, Alpine Forest, Talus Vegetated, Talus Fine, Talus Coarse, Talus Blocs, Boulder Field, Mountain Road, Asphalt, Bedrock, River/Swamp and Snow.

The used values have a large impact on the simulation results and therefore it is important to critically think about the chosen parameters. Please also consider chapter 4.8.4 to check for plausibility of results and how to adjust ground parameters accordingly. Exercise 5.3a shows how to define these terrain material parameters.

ASCII-raster-files will be created for both terrain parameters M_E and C_d , if specific ground parameters are assigned to shapefiles. If only the overall soil/ground material is specified, no ASCII-files will be created and used.

Exercise 5.3a: How to create a shapefile with specific terrain characterization

- Switch to 2D mode by clicking .
- Activate the project by clicking on the map once.
- Click *Draw New Polygon Shapefile* .
- Click into the project where you want to start drawing the outline of the shapefile.
- Continue drawing the shapefile in clockwise direction by moving the cursor and clicking the **left mouse button**. Finish the polygon by clicking the **right mouse button**. The polygon will be closed automatically.



Figure 5-37: Project with emerging polygon shapefile.

Before the polygon shapefile is created, you must answer the following questions:

- **Add more polygons?**
You can either answer with **Yes** and create a second polygon as explained above or answer with **No** and continue with the next step.
- **Is this polygon a hole?**
This dialog appears if you have drawn the polygon in counterclockwise direction. If this is a mistake and you want it to be an ordinary polygon, click **No** and the drawing direction is inverted. If you want to cut a hole into a polygon, first draw the outer polygon in clockwise direction, then select **Yes** when asked **Add more polygons?**, draw the hole in counterclockwise direction and select **Yes** when asked **Is this polygon a hole?**
- **Choose a new polygon file name:**
Enter a new name according to the terrain material represented by the polygon(s) (e.g. bedrock). The ending *.shp is added automatically. The polygon shapefile will now be created and added to the project directly.
- Alternatively, you can draw the polygon shapefiles in a GIS software and load them directly with **GIS -> Import Shapefile** or by clicking .
- Assign a soil category to a specific shapefile by right clicking on its name in the file tree and choosing **Set Soil** followed by choosing either a default soil type or **Edit Soil**, where custom combinations of M_E and C_d can be entered. This soil category will be applied to all polygons of the shapefile. If you want to choose individual soil categories for the

polygons in the shapefile, use the **Edit Soil Parameters tool**  in the top toolbar and click into the specific polygons.

5.6.1 Creating Custom Soil Types

After choosing a soil type, users can change M_E and C_d -values and colors (with **Edit Soil**) and then save the changes as a new custom soil, within the original soil category.

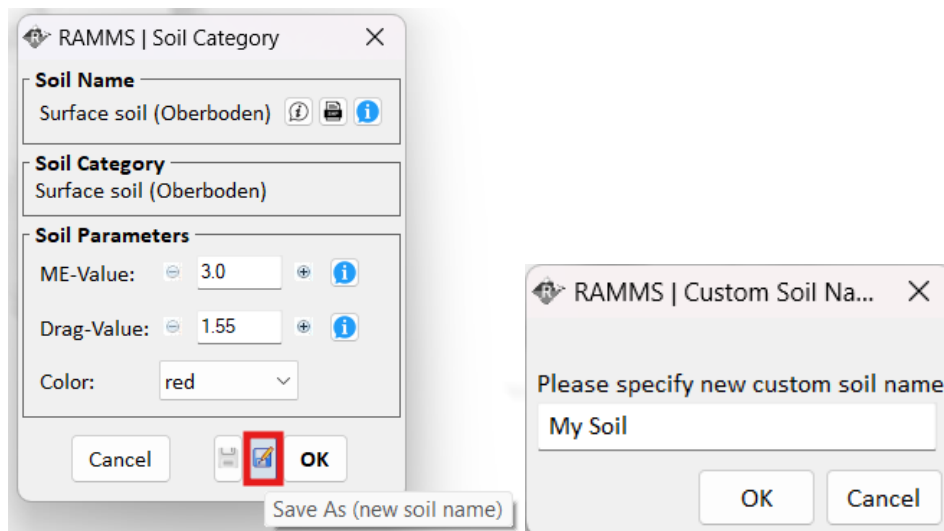


Figure 5-38: Save new custom soil type

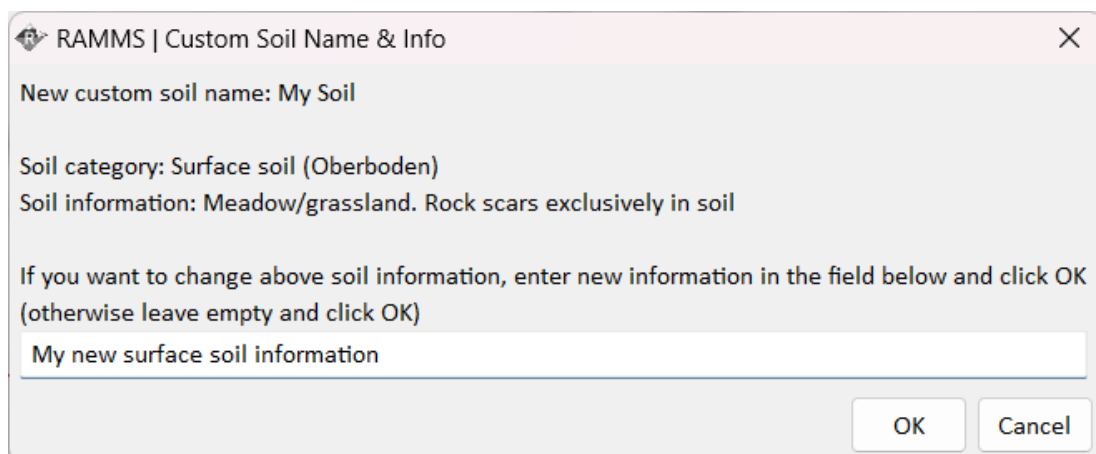


Figure 5-39: Updating custom soil information

Your custom soil types are then saved as a xml-file in your userprofile-directory. If you want to delete a custom soil type, choose **Input** → **Soil/Forest Parameters...** → **Edit my Custom Soil Types**.

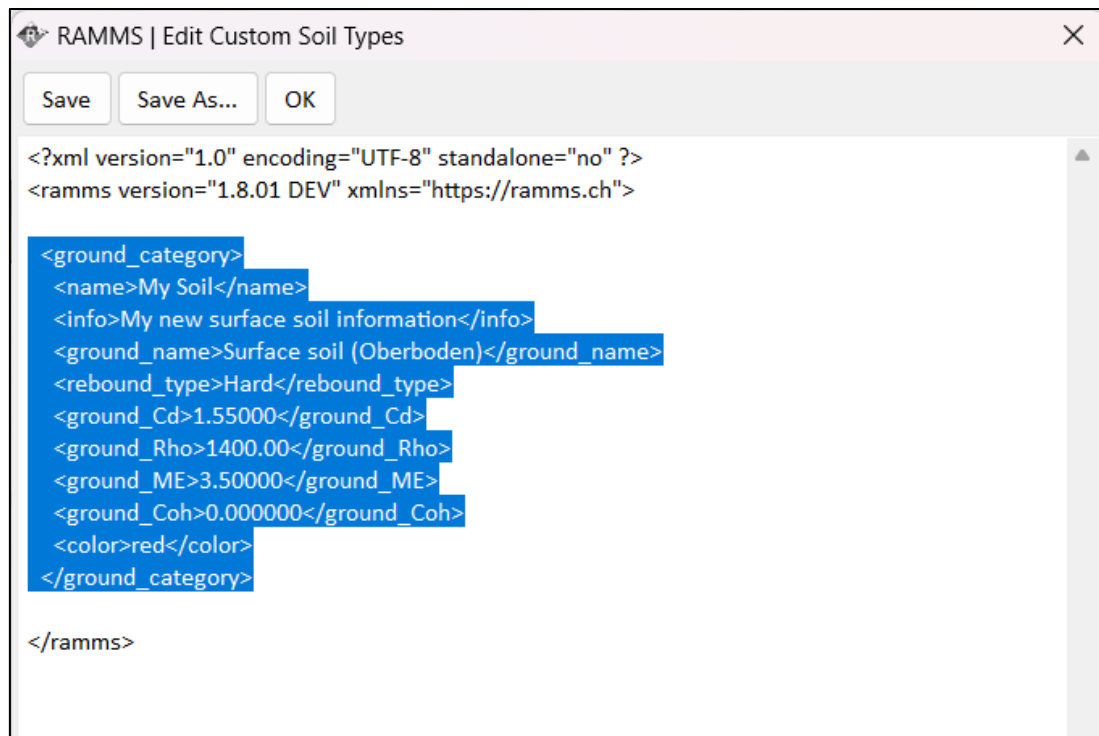


Figure 5-40: Delete custom soil types by removing one or all <ground_category> blocks as highlighted above. Click Save and OK.

5.7 Forested area

Forest has a major impact on runout and velocities of rockfalls. To include forested areas into a RAMMS simulation you need to specify the areas as polygon shapefiles as described in Exercise 5.3a. Create a polygon shapefile (see chapter 5.4.1) or import it from other projects or from GIS (see chapter 5.4.2). Choose appropriate filenames for the different shapefiles while generating them so there is no confusion about which shapefile belongs to which terrain type or forest.

5.7.1 Creating Forest Shapefiles

To assign a forest to a polygon shapefile you can either:

- **Select the edit forest parameters tool  in the top toolbar and click into a polygon.** With this tool, you can assign different forest parameters to polygons of the same shapefile. Only the selected polygon will be assigned to the forest parameters.
- **Right-click on the shapefile in the file tree in the right panel and select Set Forest.** If a shapefile consists of several polygons, all polygons will be assigned to the chosen forest type.

This shows a list where you can either choose a default forest type or enter custom tree densities and BHD distributions by choosing **Edit Forest**.

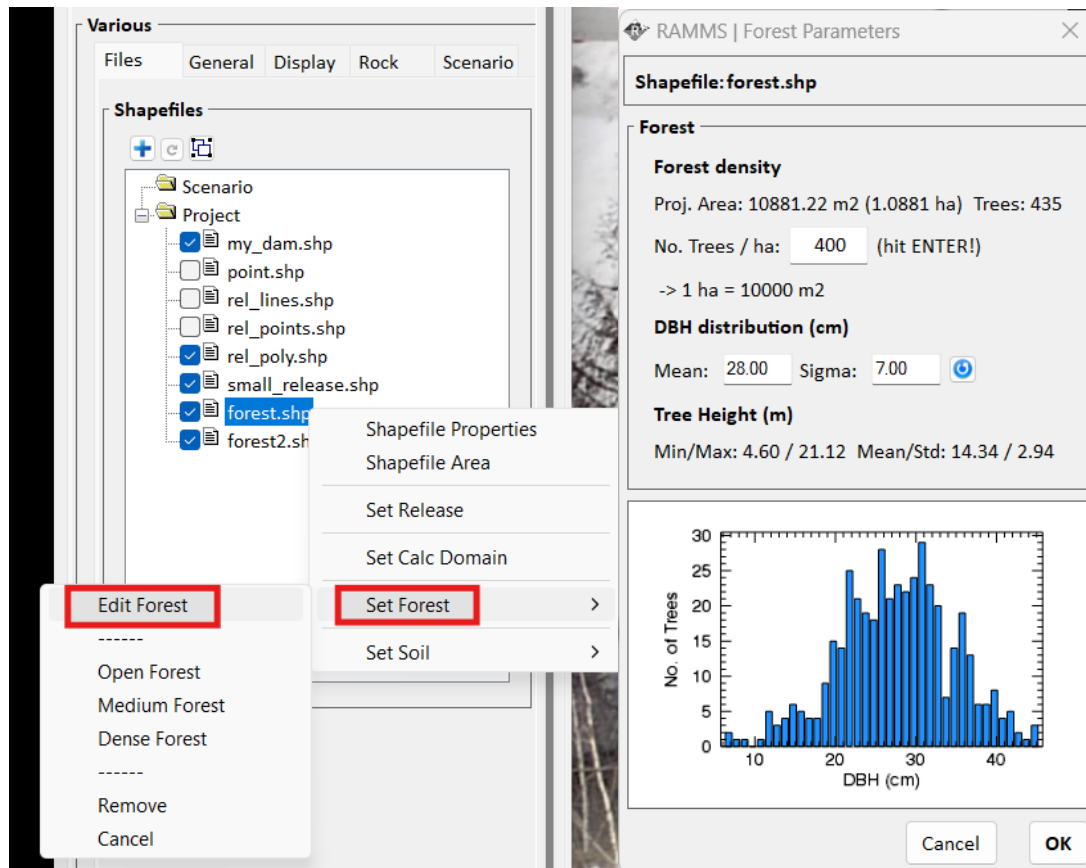


Figure 5-41: Assigning a forest type to a polygon shapefile from the file tree (left) and dialog to enter custom forest densities and DBH distributions (right).

5.7.2 Forest Parameters

The **Forest Parameters** dialog (see Figure 5-41) shows:

- The area of the selected polygon and the number of generated trees according to the entered tree density (2).
- The tree density [trees/ha]
- Mean diameter at breast height (DBH) and standard derivation for the Gaussian distribution. If one of the parameters is changed, a new distribution is generated automatically and shown in (5). Click  to generate a new random distribution without changing any parameters.
- Statistical values of the calculated tree heights based on the generated DBHs. The height of a generated tree is: $H_{Tree} [m] = DBH [cm]^{0.8}$
- Histogram of the DBH of the generated trees based on the parameters defined in (3).

RAMMS::Rockfall will generate the forest according to the defined tree density and DBH distribution. Detailed information about forest modelling can be found in section

4.9. Note that creating a forest does not influence the soil properties within the shapefile. This means that if you do not specifically assign a terrain material to a forest shapefile, the global soil property is used.

5.7.3 Forest Visualization

Forests can be visualized in two ways. In the default visualization, the forest polygons are filled with a dotted pattern. The density of the pattern indicates the density of the forest. If you want to visualize the single trees, choose the top navigation bar **Show -> Show Trees**. Be aware that this may take some time, depending on the number of trees that need to be visualized.

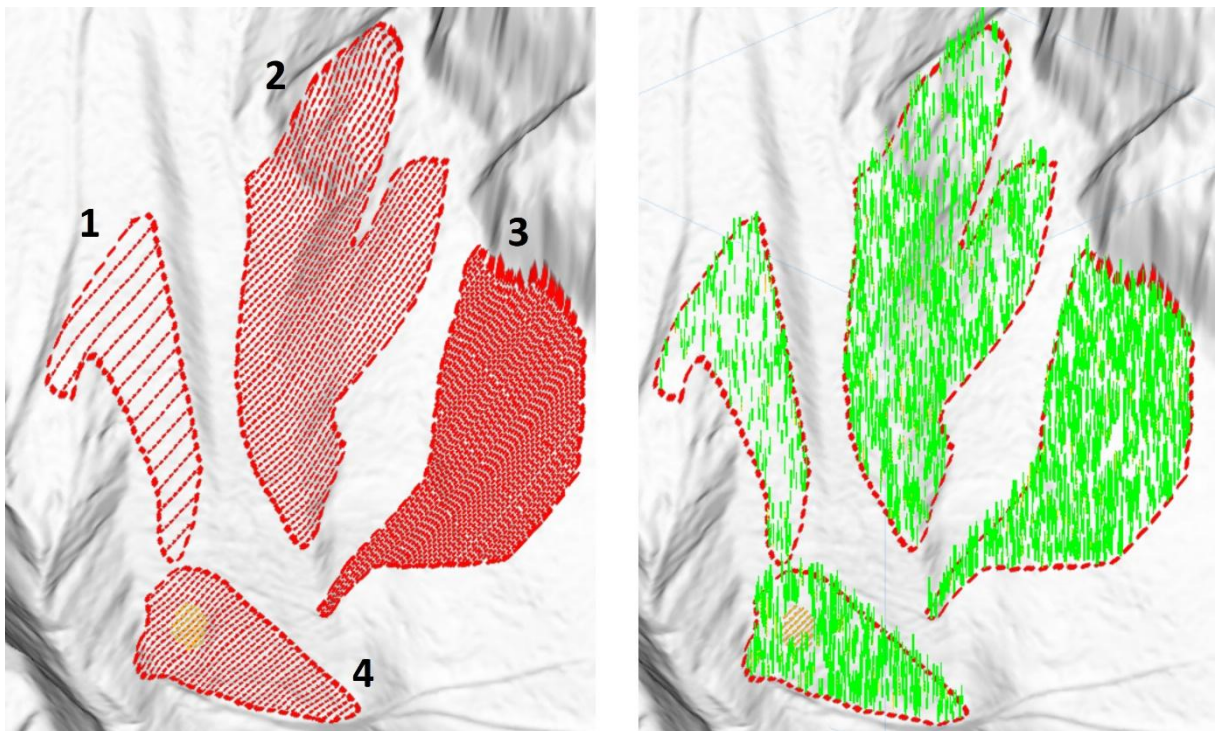


Figure 5-42: Default forest visualization (left) and visualization with single trees (right). The forest types in this example are (1) Open forest, (2) Medium forest, (3) Dense forest and (4) Medium forest with a clearing/hole shown with yellow dotted pattern.

5.7.4 An Example of Using Forests

Exercise 5.4b: How to assign a forest to a shapefile

- **Switch to 2D mode**
Click the 2D mode icon 
- **Activate the project**
Click anywhere on the map to activate the project

- **Draw a New Polygon Shapefile**

Click the *Draw New Polygon Shapefile* button .

- **Start Drawing the Polygon**

Click on the map where you want the polygon outline to begin.

- **Continue Drawing the Polygon**

Move your cursor and click the **left mouse button** to define each corner of the polygon. Complete the shape by clicking the **right mouse button** — the polygon will close automatically.



Figure 5-43: Project with emerging polygon shapefile (left, middle) and assigned dense forest (right).

Before the shapefile is created, you'll be prompted to:

- **Add more polygons?**

Click **Yes** to draw additional polygons using the same process, or **No** to finish.

- **Is this polygon a hole?**

This prompt appears if the polygon was drawn in a **counterclockwise** direction.

- Click **No** to convert it to a regular polygon (direction will be corrected automatically).
- Click **Yes** only if you're intentionally creating a hole inside an existing polygon. In that case:
 - First draw the outer polygon **clockwise**,
 - Then draw the inner polygon **counterclockwise**,
 - Answer **Yes** to both prompts: *Add more polygons?* and *Is this polygon a hole?*

- **Choose a file name**

Enter a name that reflects the type of forest (e.g., dense_forest). The .shp file extension is added automatically. The shapefile will be created and added to your project.

Alternative Method

You can also create shapefiles using an external GIS software and import them into your project by

- Clicking **GIS → Import Shapefile**, or

- Clicking the **Import Shapefile** button 

Assigning Forest Properties

- To assign a forest type to the whole shapefile:**
Right-click the shapefile name in the file tree → **Set Forest**.
Choose a **default forest type**, or select **Edit Forest** to define custom parameters (e.g., tree density, DBH distribution).
- To assign different properties to individual polygons in the shapefile:**
Use the **Edit Forest Parameters** tool  in the top toolbar.
Click on individual polygons and assign a forest type or enter custom parameters (see section 0 above).

Optional: Assign Soil Type

You can assign a soil type to the new forest following **Exercise 5.3a**. If no soil type is defined, the global soil properties will be applied by default.

Forest input requires a polygon shapefile defining the forested area and a parameter set for stem density and mean DBH. RAMMS distributes trees randomly within the polygon. Run multiple realisations (different random seeds) to average out stochastic variability in tree placement, especially for small forest patches.

5.8 Rock builder

RAMMS offers the **Rock Builder** to create realistic point cloud files from predefined rock shapes. We strongly recommend using the *Rock Builder* instead of using spheres or cuboids for rockfall simulations as the rock shape has major impact on the output of the rockfall simulations with RAMMS. There are already several realistic rock shapes included in the library. Exercise 5.5 demonstrates how to create a realistic rock shape with the Rock Builder tool. The rock mass and volume for realistic rocks have to be defined in the *Rock Builder* and have to be saved in the rock .pts file. You cannot change the rock volume or mass afterwards.

5.8.1 Using the rock builder

Exercise 5.5: How to create a rock with the Rock Builder

- Click  to open the **Rock Builder**.

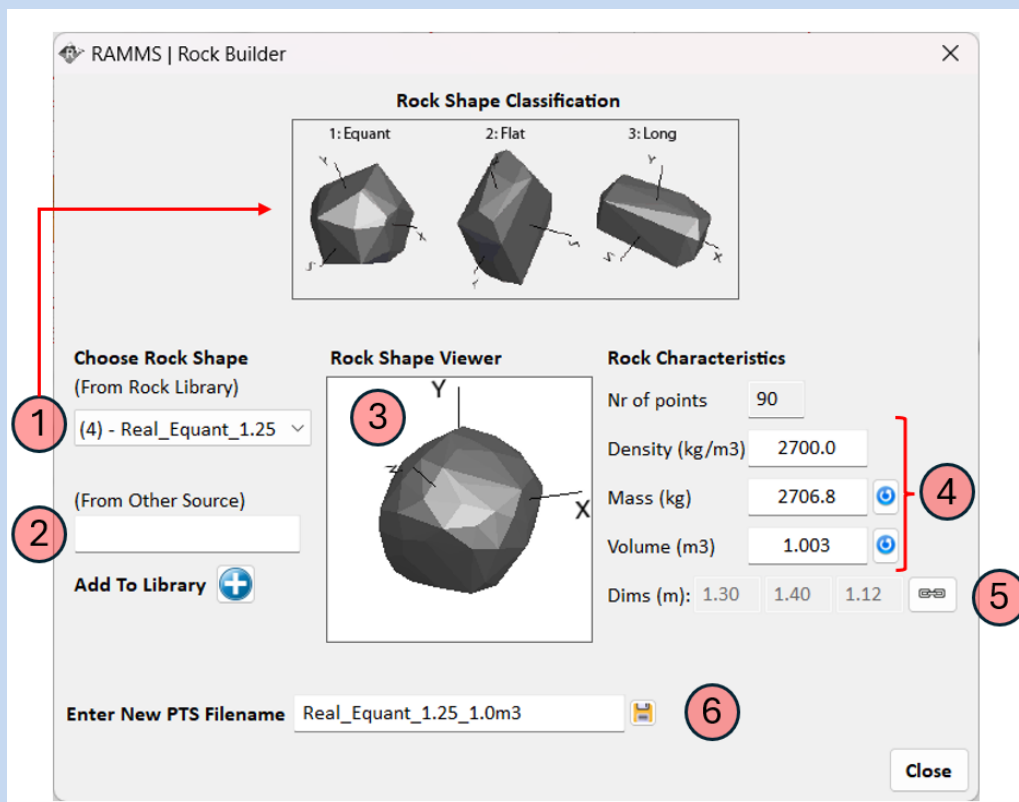


Figure 5-44: Rock Builder

- Select a predefined rock shape from the rock library (1) or select a .pts-file of a rock shape from another source (2). You can then add this rock to your rock-library by clicking **Add To Library**. This rock-library is then saved in your Windows-Userprofile.
- By pressing the left mouse button and moving the mouse you can move the 3D visualization of the rock interactively and look at it from any direction (3).
- The rock has predefined initial rock characteristics (4). When changing the rock density, the *Rock Builder* automatically calculates the new mass of the rock. After changing the mass of the rock, click  to adjust the volume and the dimensions (X/Y/Z) of the rock. Enter a new rock volume and click  to adjust the rock mass as well as the rock dimensions (X/Y/Z). Be aware that

the *.pts file format only saves the rock vertices. Mass and density information are therefore not saved after constructing the rock with the rock builder. The density and mass fields are therefore only a help to calculate the preferred volume of the rock. If you want to use a different density than the default for your simulation, you must adjust it in the “Run Simulation” dialog (see Figure 6-8)

- Change axes of rock (5)
Click on the button next to the rock dimensions (unlock aspect). Now you can change the rock’s axes. Press ENTER after changing an axis, such that the view of the rock is updated, and volume and mass are calculated accordingly.
- Enter a file name or use the suggested name and click  to save the new .pts-file (6). RAMMS automatically creates a **rocks** folder in your project directory. It’s strongly recommended to save your new rocks in this directory.
- Click **Close** to close the *Rock Builder* window.

Once a rockfall simulation has been finished and opened in RAMMS, you can find additional information on the rock for every trajectory in the *ROCKFALL* panel, tab *Rock*, see Figure 5-45. Use the left mouse to move the visualization rock in any direction.

Please be aware that you must be in *Trajectory-mode* and activate a specific trajectory to get information about the rock type.

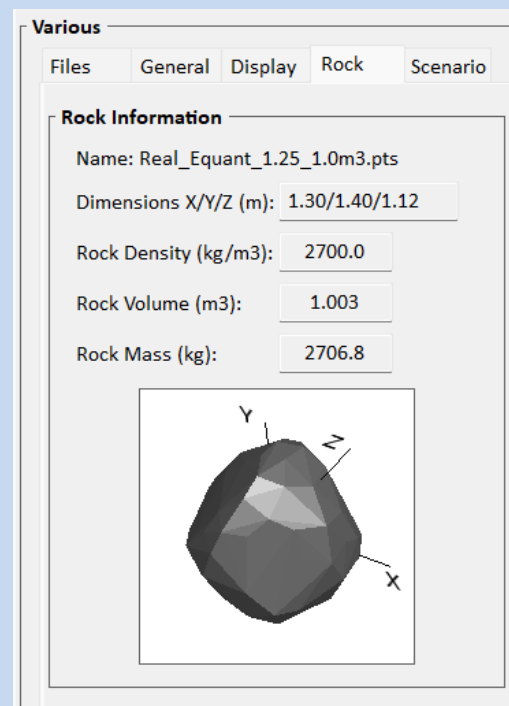


Figure 5-45: Rock Information

Edit custom rock library

For now, you can edit your custom rock library manually by using this feature:

Extras → Edit my Rock Library

Your rock library (xml-file) will then be shown in a text editor, see Figure below. You can remove `<rock>`-sections, **save** it, click **OK** and then restart RAMMS, for changes to take effect. Please make sure that you do not delete `</ramms>` at the end of the document, or any other line (otherwise the xml-file will be corrupted).

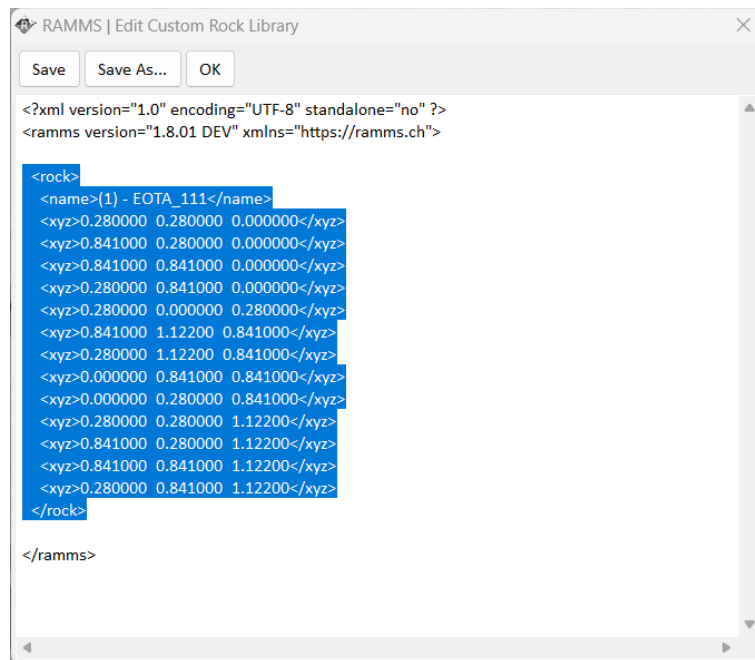


Figure 5-46: Edit your custom rock library. Remove `<rock>`-sections if needed, as highlighted above.

The Rock Builder generates point cloud files (.pts) representing realistic rock shapes from a set of predefined primitives scaled by user-defined axes (a, b, c). Use the Rock Builder to create a consistent set of rock shapes for a scenario rather than relying on a single ellipsoid approximation.

5.8.2 Convex hull (point cloud) rigid obstacles

In RAMMS, *convex hull objects* are used to represent rigid obstacles such as:

- **Barriers (including nets)**
- **Dams**
- **Rockfall sheds**
- **Any other structure that can interact with falling rocks**

These objects are geometrically represented as **convex shapes**, meaning all interior

angles between surface points are less than or equal to 180° , and any line drawn between two points inside the object lies completely within the object.

RAMMS uses a **point cloud** to define the geometry of these objects. The system automatically generates a **convex hull** around the provided point cloud to simplify and speed up collision detection and impact calculations.

Important: Only **convex** shapes are supported. Concave geometries or objects with internal cavities are still represented as convex hulls, and might look different than expected.

5.8.3 Creating Point Cloud Objects Outside of RAMMS

While RAMMS provides tools to create dams and other convex hull objects internally (e.g., via shapefiles and elevation input), you can also generate these objects externally using your own geometry and import them into RAMMS.

To do this, you need two files:

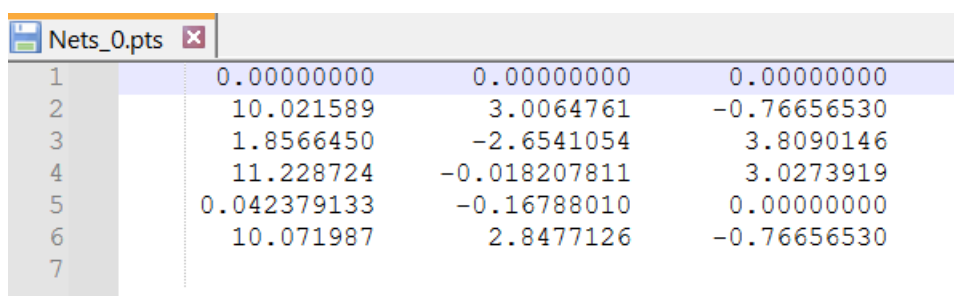
- **The .pts File – Point Cloud Data**

This file contains the relative coordinates of the object's surface points in the format:

```
x1  y1  z1
x2  y2  z2
...
```

Each line represents one point in 3D space. The coordinates are **relative**, meaning the first point is assumed to be at **0.0 / 0.0 / 0.0**, and all subsequent points are defined relative to it.

Example (Net_0.pts):



1	0.00000000	0.00000000	0.00000000
2	10.021589	3.0064761	-0.76656530
3	1.8566450	-2.6541054	3.8090146
4	11.228724	-0.018207811	3.0273919
5	0.042379133	-0.16788010	0.00000000
6	10.071987	2.8477126	-0.76656530
7			

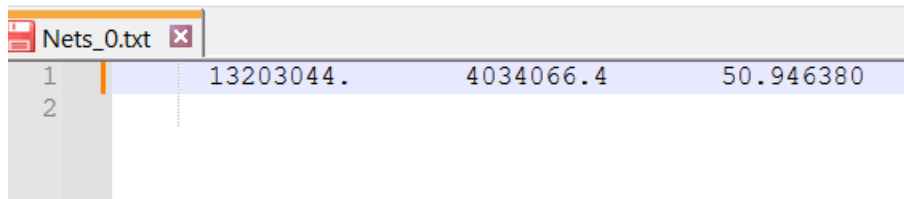
Figure 5-47: Example pts-file

- **The .txt File – Absolute Reference Point**

This file stores the **absolute coordinates (X0, Y0, Z0)** of the first point in the point cloud, expressed in meters in the global Cartesian coordinate system.

RAMMS uses this file to **place the object correctly** in the simulation domain.

Example (Net_0.txt):



1	13203044.	4034066.4	50.946380
2			

Figure 5-48: Example pts-reference file

This means that the first point of the .pts file (which is at 0/0/0) is located at the absolute position X = 13203044, Y = 4034066.4, Z = 50.94638 m.

The .pts and .txt files must have the **same base filename** (e.g., Net_0.pts and Net_0.txt) to be correctly recognized by RAMMS.

5.8.4 Importing External Convex Hull Objects into RAMMS

To load externally created objects into RAMMS:

- Place the .pts and .txt files in your project directory.
- Add the Barrier/Dam/Shed obstacle in RAMMS.
- Select your .pts file(s). RAMMS will automatically read the associated .txt file.
- Optionally, you can select multiple .pts files (hold Shift) to apply the same properties to several objects at once.

Notes and Best Practices

- These objects behave identically to internally created dams, galleries, or nets.
- Make sure that the point cloud forms a valid convex shape—otherwise RAMMS may generate unexpected results.
- Use enough points to define the object accurately, especially for long or sloped surfaces.
- Naming consistency is crucial: the .pts and .txt must have matching names.

5.9 Barrier objects (nets)

RAMMS models nets as “thin wall” objects (see Figure 5-49), as rigid obstacles. These “thin wall” objects are modeled as convex hulls (point clouds). A separate barrier object is created for each net field, from support post to support post (see Figure below).

Net objects are represented by a prism-like Qhull volume, where the base is terrain-following and slightly embedded below the surface instead of being defined only by the post endpoints and a shifted base line. This reduces gaps below the net and helps prevent rocks from passing underneath the obstacle on irregular terrain.



Figure 5-49: Example of rockfall net



Figure 5-50: Rockfall net support posts

The angle (α) between the support and the terrain can be defined according to this sketch from Geobruigg.

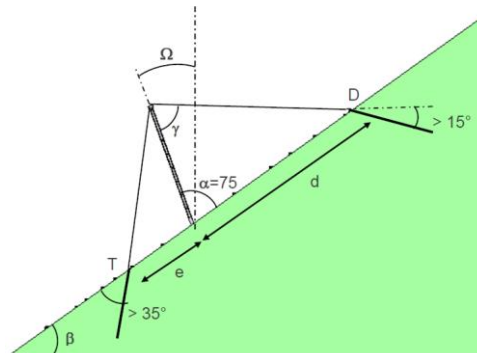


Figure 5-51: The default angle between the terrain and the post is 75° (sketch provided by Geobruigg).

5.9.1 Energy Absorption Capacity

For each line shapefile (and its corresponding net objects), an energy absorption capacity can be specified (in kJ), see Figure below:

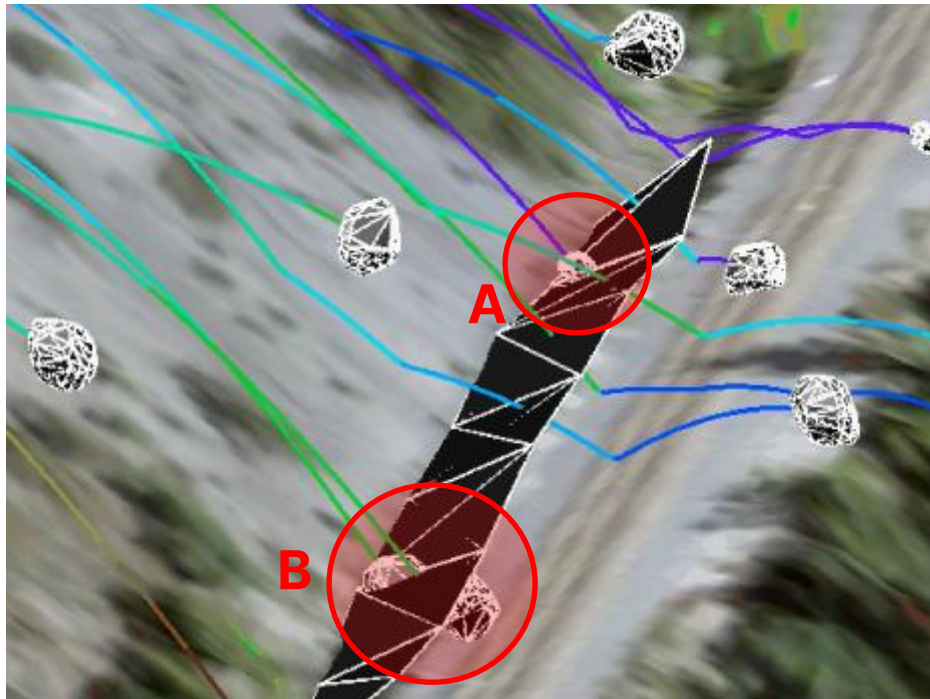


Figure 5-52: Rockfall nets with an energy absorption capacity of 1'000 kJ. Small rocks are stopped (A), but larger ones pass through (B).

If the kinetic energy of the rock is lower than this limit, the rock is stopped (A). If this limit value is exceeded by the rock, the net has no influence on the rock's trajectory, and the rock passes through the net (B).

There are two possibilities to create new barrier (net) objects:

- Draw a new line shapefile in RAMMS, and subsequently create net objects from there, or
- Use “**Input → Barriers... → Create Barriers from Line-Shapefiles**” to create net objects from already existing line-shapefiles.

5.9.2 Create new net object: Step-by-step

- (Option a): Draw a new line shapefile at the location of barriers (net) directly in RAMMS. While drawing the line shapefile, RAMMS indicates the distance from the mouse position to the selected support post, see Figure below.

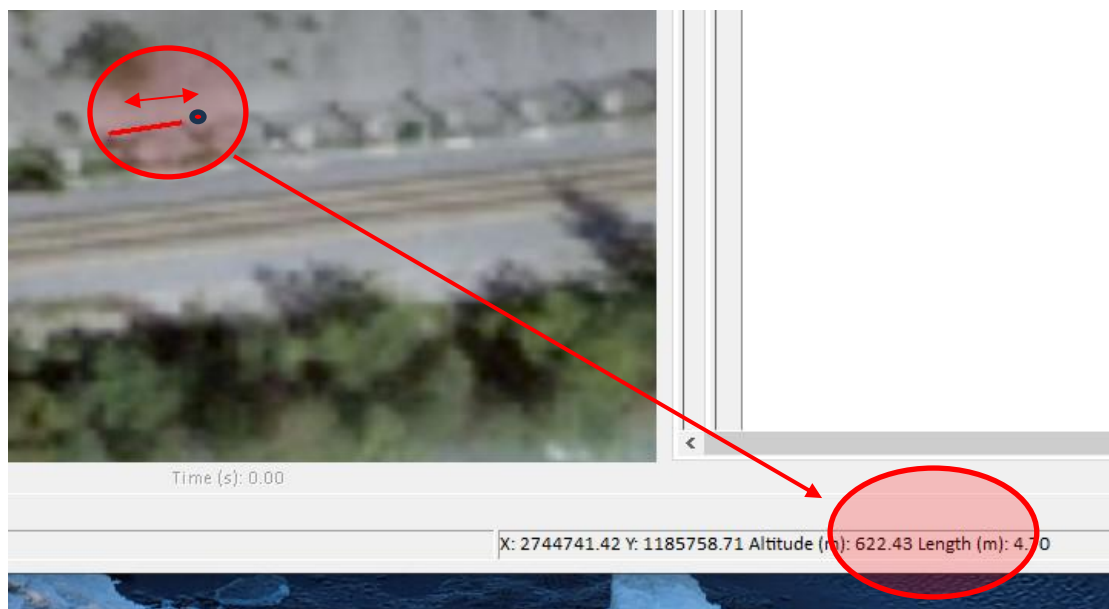


Figure 5-53: Distance measure between support posts.

- (Option a): RAMMS will then ask you if a barrier object should be created from this line shapefile.

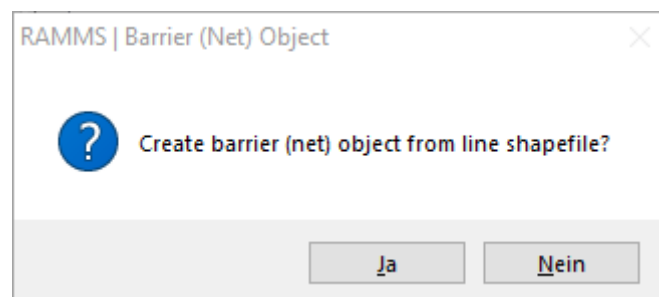


Figure 5-54: Create barrier net object from line-shapefile.

- Click Yes, and then enter barrier height (m), the angle between terrain and post (°) and the energy absorption capacity (in kJ), see figure below.

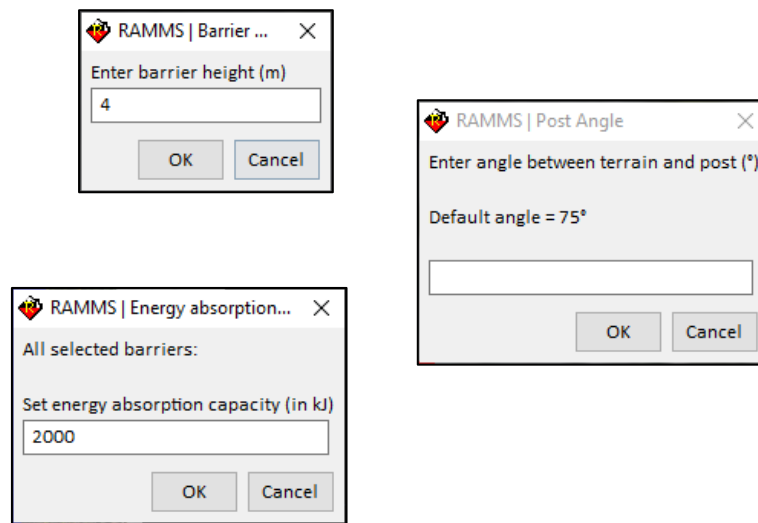


Figure 5-55: Enter barrier height, angle and energy absorption capacity.

- For every net field (from support post to support post), RAMMS creates a single convex hull (point cloud) object. The filename from the line-shapefile is used, added by an ID-number, and the file extension .pts.
- The net objects are then visualized in RAMMS, see figure below. Visualized net objects are always considered in a new simulation.

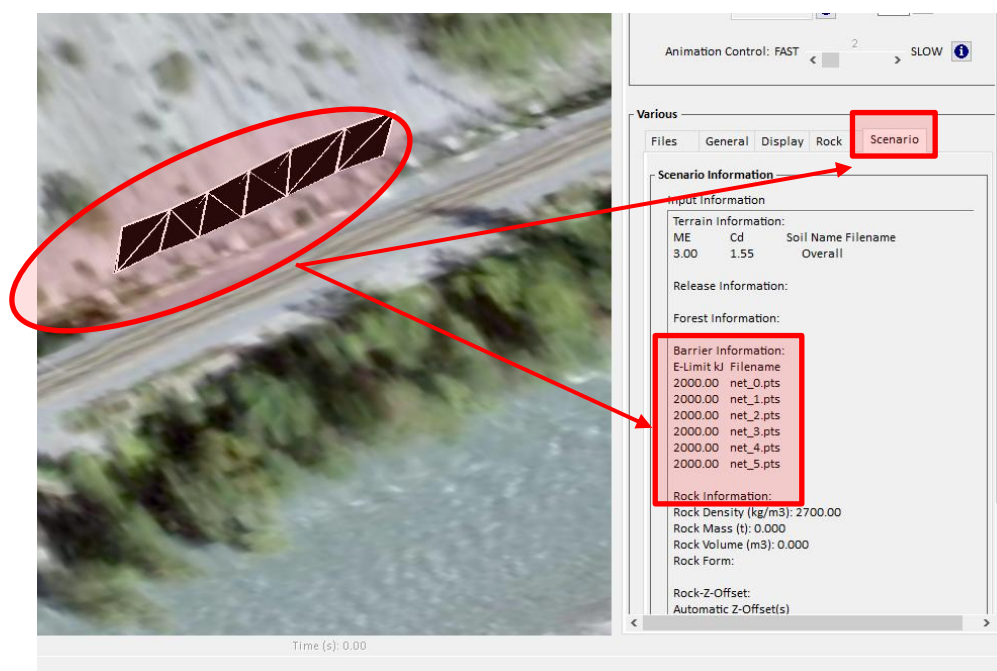


Figure 5-56: Net objects visualized in RAMMS.

- If you do not want to use net objects for a simulation, remove all barrier objects with «**Input → Remove Barriers/Dams**».
- Net objects (*.pts) can be added later to a project by using “**Input → Barriers... → Add Barriers**”. You can then specify an energy absorption capacity to the net object(s). Select multiple pts-files (by holding the Shift-Key) to assign the same energy absorption capacity to multiple nets.

5.10 Rockfall Dams, Rockfall Sheds

In many practical applications, it is necessary to incorporate **mitigation measures** into rockfall simulations to evaluate their effectiveness and their interaction with falling blocks. RAMMS::Rockfall provides dedicated modelling tools for analyzing rockfall impacts on **rockfall dams**, **rockfall sheds**, and **bridges**.

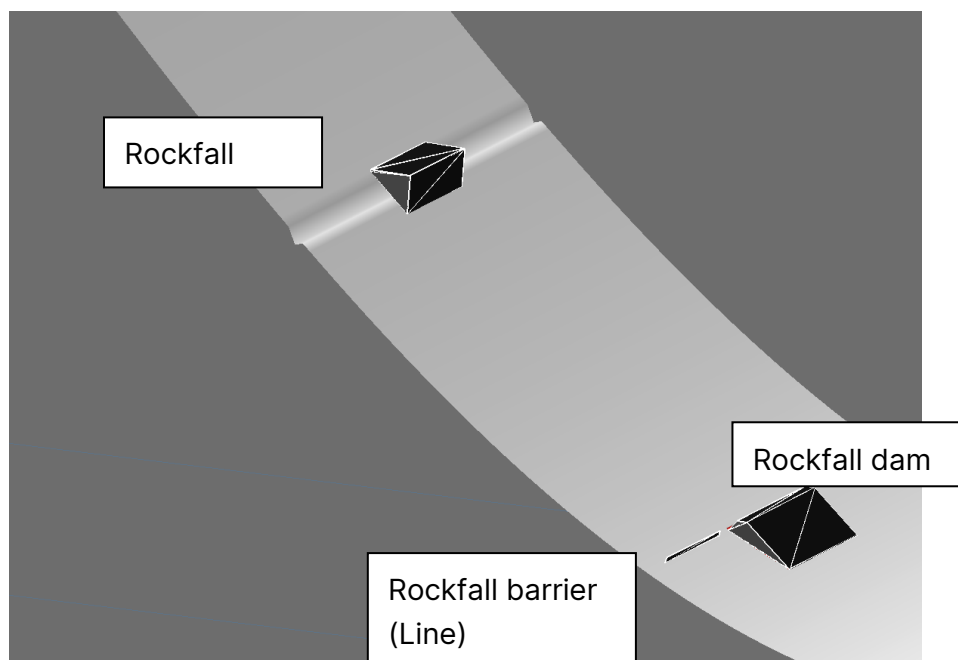


Figure 5-57: Rockfall sheds and dams can be introduced into the model domain. These obstacles are true three-dimensional rigid obstacles.

Unlike flexible barriers, which are defined using line profiles, these mitigation measures must be represented as **three-dimensional structures positioned within the model domain**. Rockfall dams and sheds are treated as rigid, artificial obstacles that are embedded into the terrain model. During a simulation, these structures can intercept, deflect, or stop falling rocks, depending on their geometry and energy absorption capacity. **Impact information**, such as the **number of impacts**, **impact angles**, and **impact energies**, can be evaluated for both dams and sheds (see Sections 7.5.1 and 7.5.2).

Bridges can be considered a special case of a rockfall dam. In this configuration, the dam base is not embedded in the ground but elevated above it, creating an underpass beneath the structure. **RAMMS::Rockfall** includes specialized analysis tools to evaluate impacts on rockfall sheds, dams, and bridges, accounting for their geometry and structural characteristics.

Figure 5-57 illustrates an example model domain containing both a rockfall shed and a rockfall dam. The user may specify a single obstacle, or alternatively a mix of one or more obstacles in a single domain. Dedicated input tools are available within the software to facilitate the definition of shed, dam, and bridge geometries.

For both object types, the interaction with falling rocks is limited by a maximum kinetic energy that can be absorbed by the structure. If **the kinetic energy of an impacting rock exceeds this energy absorption capacity, the obstacle is assumed to lose its effectiveness**. In this case, the impact is recorded, but the obstacle no longer influences the rock's subsequent motion, and the simulation continues as if the obstacle were not present.

Dams and sheds can be specified under **Input → Dams...** or **Input → Sheds...**, directly beneath the **Input → Barriers** menu:

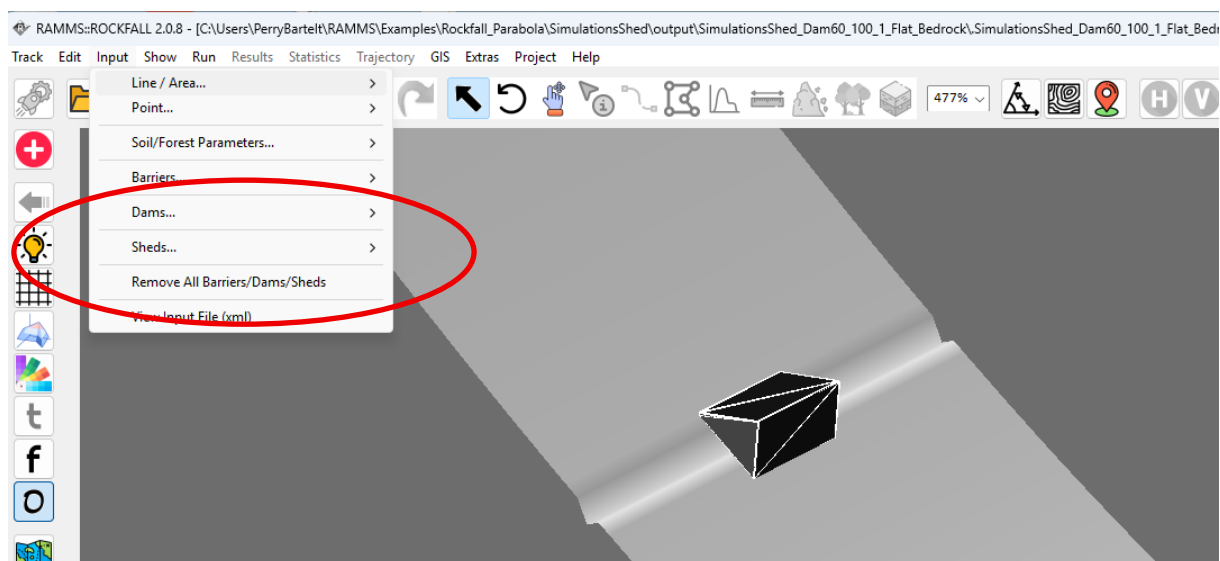


Figure 5-58: Rockfall sheds and dams are specified using the under Input → Dams... or Input → Sheds...

The definition of dams and sheds consists of two fundamental steps. First, **the location and geometry of the dam or shed are specified** (e.g. position, elevation, face inclination, and crest width). Second, **the structural response parameters governing the interaction with falling rocks are defined**, including the **energy absorption capacity** (kJ), **compression modulus** (ME, in MN/m²), and **energy dissipation factor**. These parameters are then used to compute the **resistance force factor** (C_d), **area of impact** (A), and **penetration depth** (d) which can be output for structural analysis.

IMPORTANT: All dams and/or sheds that are created by the user can be removed from the simulation by using the *Input->Remove All Barriers/Dams/Sheds*.

5.10.1 Defining Dam Location and Geometry

The location and geometry of a dam can be defined using four different methods, depending on how the structure is embedded in the terrain (see Figure 5-59):

1. Addition of a *.pts Point-Cloud File (convex hull)

A ***.pts Point-Cloud File** representing the dam geometry can be **added** directly to the terrain via ***Input → Dams... → Add Existing Dams***.

2. By Defining Inclination, Elevation, and Crest Width

Navigate to ***Input → Dams... → Create Dam (Inclination/Elevation/Width)***. Specify the main dam face's inclination, the constant elevation of the dam crest, and the crest width. Only the dam foot shapefile is required.

3. From Shapefiles (Elevation)

Navigate to ***Input → Dams... → Create Dam (Elevation)***. Specify the dam crest's horizontal elevation (in meters above sea level). Both the dam foot and dam crest shapefiles must be provided.

4. From Shapefiles (Relative Height)

Navigate to ***Input → Dams... → Create Dam (Relative Height)***. Define the relative (constant) height difference (in meters) between the dam foot and crest. Both the dam foot and dam crest shapefiles must be provided.

The last three methods indicate that dams can be created within RAMMS using polygon shapefiles generated externally (e.g. in GIS software) or drawn directly in RAMMS via ***Input → Line / Area... → Draw New Polygon Shapefile***. A figure illustrating the dam input menu and the four available options is provided below.

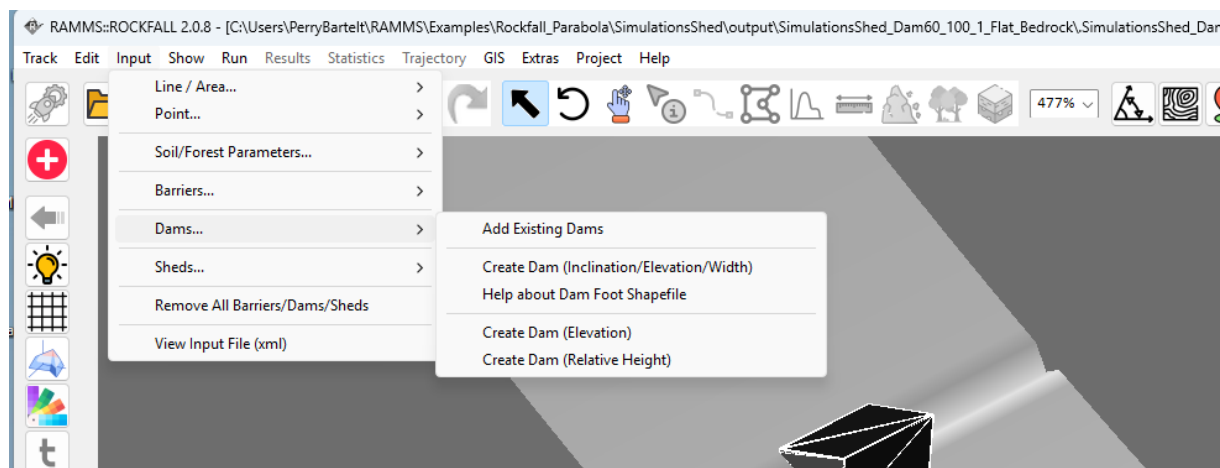


Figure 5-59: There are four methods to create a dam in the model domain: (1) Add Existing Dam (add an existing point cloud), (2) Create dam (only dam foot required), (3) Create dam (Elevation) from two shapefiles, (4) Create Dam(Relative Height) from two shapefiles.

When **creating** a dam (options 2–4), as opposed to **adding** a dam using a point-cloud file (option 1), the user must create one or two polygon shapefiles. One shapefile

defines the dam foot, and the other defines the dam crest (see figure below). If the dam is defined using the face inclination method (option 2), only the dam-foot shapefile is required.



Figure 5-60: Dam crest polygon-shapefile (left), and dam foot polygon-shapefile (right)

For all creation options, the dam-foot shapefile must be constructed as described below.

Drawing the Dam Footprint Shapefile

- Switch to 2D mode and draw the dam foot shapefile by creating a new polygon.
- The order of vertices is important: draw them in the sequence from Point 1 to Point 4, as shown in Figure 5-61.
- This polygon represents the dam foot outline.
- If the dam terrain is irregular (on the face side), you may add more points along that edge (e.g. 3, 4, 5, 6, etc.) but ensure they form a straight line.
- The line between Point 3 and the last point is used to determine the orientation of the dam face.

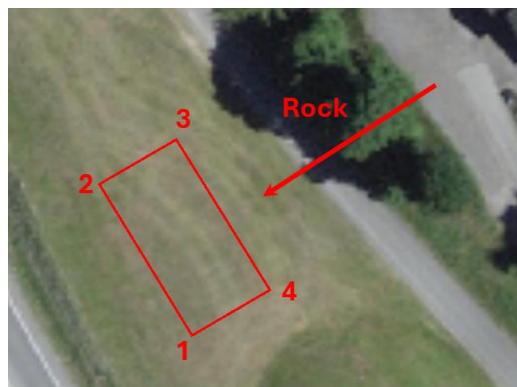


Figure 5-61: Dam footprint points order. Note the points are drawn in a counter-clockwise

IMPORTANT: The points in the footprint file determine the elevation of the footprint surface. The elevation between these points is interpolated linearly, forming a straight line from one point to the next. If only two points are selected, this linear interpolation may result in an unintended depression beneath the dam, potentially creating a hole. See Figure 5-62

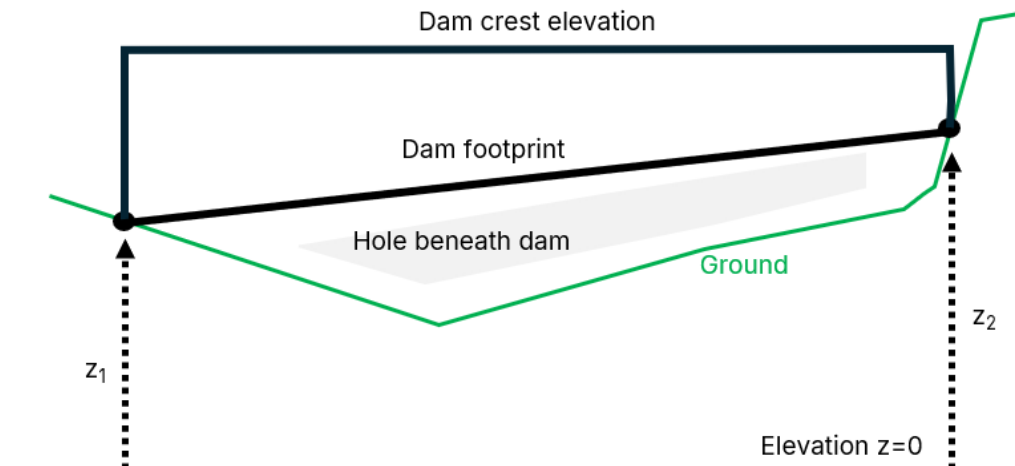


Figure 5-62: If two few points are selected to define the dam footprint, a hole might exist below the dam. In the simulations rocks will appear to pass the dam.

This problem can be remedied by selecting more points along the edges of the dam footprint, see Figure 5-63

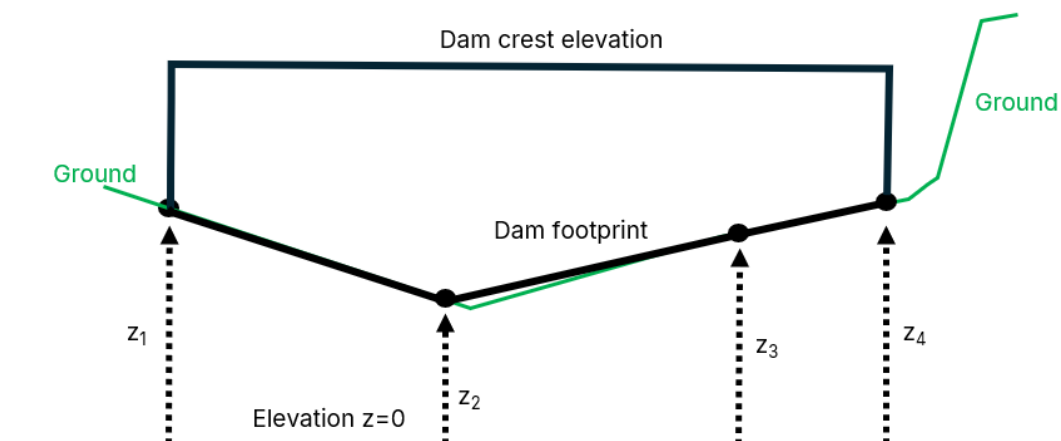


Figure 5-63: Holes can be removed from beneath the dam by creating more points along the dam footprint.

Option 1: Add *.pts Point Cloud

A dam or shed geometry can be imported directly into **RAMMS::Rockfall** using a point-cloud file (*.pts) that represents the convex hull of the structure (see Section 5.8.2).

This method allows the user to define the full three-dimensional geometry of an existing dam or shed without recreating it manually within RAMMS.

The *.pts point cloud may be generated using external software (e.g. CAD or GIS tools) or created manually by entering individual point coordinates into a text file. The point cloud defines the relative geometry of the structure only. By definition, **the first line of a *.pts file must be the coordinate (0, 0, 0)**, and all subsequent points are specified relative to this origin. The absolute position of the dam or shed within the simulation domain is defined separately using an accompanying *.txt file. This **file contains the absolute coordinates of the first point** and is required whenever a *.pts file is imported. Together, the *.pts and *.txt files fully define the location and geometry of the structure in the model domain.

When a dam or shed is created interactively within RAMMS, the software automatically generates the corresponding *.pts and *.txt files and stores them in the scenario directory. These files can later be reused and re-imported using the **Add .pts Point Cloud* option.

This method is particularly useful for quickly importing existing dams or sheds with known geometry and location. While adding a point cloud defines the structure's geometry and placement, the **structural response parameters** (e.g. energy absorption capacity, compression modulus, and energy dissipation factor) must be specified again by the user. Consequently, this option is most used when investigating multiple structural parameters for a dam or shed with fixed geometry and location, such as in sensitivity or design studies.

Option 2: Create Dam (Inclination/Elevation/Width)

Once the foot shapefile is defined (see instruction above), RAMMS will prompt for the following input parameters:

1. Setting Dam Parameters

Inclination Angle of Dam Face

- Define the angle of inclination (in degrees) of the dam face.
- Default = 70° if no value is entered.

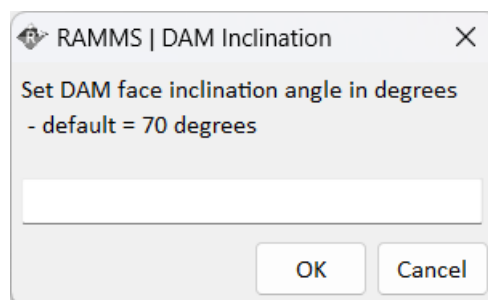


Figure 5-64: Dam face inclination angle

Dam Crest Altitude

- Enter the absolute elevation (in m a.s.l.) of the dam crest.
- The elevation is assumed to be constant (horizontal).
- RAMMS calculates the mean altitude of the dam foot face points and displays it for reference.

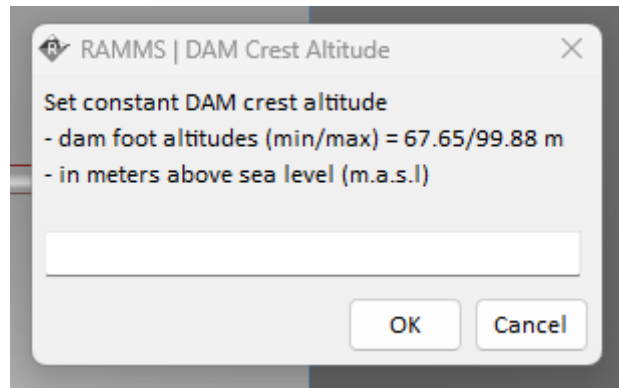


Figure 5-65: Specification of dam crest altitude. The window provides information of the footprint altitude. In this case the upper dam face is located at 99.88m elevation.

Dam Crest Width

- Define the width of the dam crest in meters.
- Default = 3.0 m if left blank.

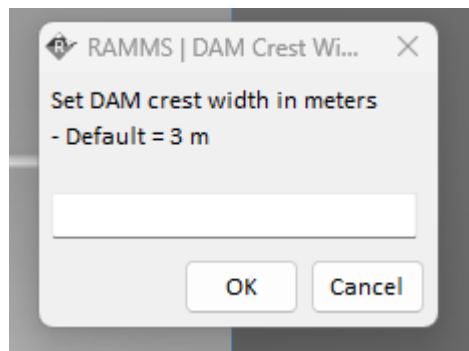


Figure 5-66: Input window for the dam crest width.

Once the dam crest width has been defined, the program will generate and save the corresponding dam geometry. If a file with the same name already exists, the user will be prompted to confirm whether the existing file should be overwritten.

Following this step, the user will be required to define the structural properties of the dam. These parameters include the dam's energy absorption capacity (failure energy),

expressed in kJ, as well as the M_E value, specified in MN/m². These inputs are essential for accurately characterizing the mechanical performance of the structure.

At this stage the dam is depicted in the model domain. Both 2D and 3D visualizations are possible.



Figure 5-67: Dam-visualization in RAMMS - Dam.pts.

Option 3 and 4: From Shapefiles (Elevation/Relative Height)

For Options 3 and 4, the dam crest geometry must be provided as a polygon shapefile. To ensure correct processing, this file must meet the following requirements:

1. **Location within the footprint**

The crest polygon should generally be located inside the dam footprint polygon. In practice, the crest represents a sub-area of the footprint and must therefore lie within its boundaries.

2. **Consistent point ordering**

The crest shapefile must follow the same vertex ordering (point sequence and orientation) as the footprint shapefile. This consistency is essential for the program to correctly interpret the geometry. For example, if the first vertex of the dam footprint polygon is located at the lower right-hand corner, then the first vertex of the crest polygon should also begin near the lower right-hand side. Maintaining a consistent starting point and rotational direction allows the program to correctly identify the upstream and downstream faces of the dam.

Failure to follow these conventions may result in incorrect identification of the dam face and unintended geometric errors. For the creation process with these options:

- **Select the dam foot polygon-shapefile, and afterwards the dam crest polygon-shapefile.**
- **Select a name for your dam. This name will be used for the point-cloud-file.**

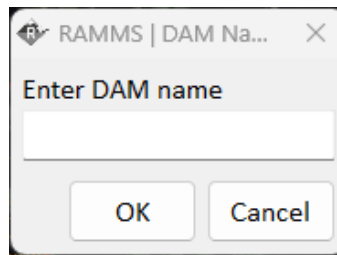


Figure 5-68: Enter new dam name

Once the dam footprint has been defined, RAMMS automatically generates:

- A .pts point-cloud file representing the convex hull geometry of the dam.
- A .txt reference file, which stores the real-world coordinates of the origin (first point in the point cloud).
- The .pts file contains relative coordinates (starting from 0/0/0).

If files with the same name already exist, RAMMS will prompt whether to overwrite them. The two options differ regarding the last input. In Option 3, the user is requested to specify an elevation,

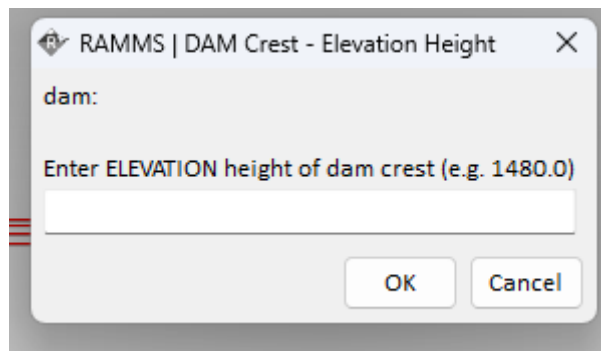


Figure 5-69: Specification of dam crest elevation.

whereas with option 4, the relative height is requested:

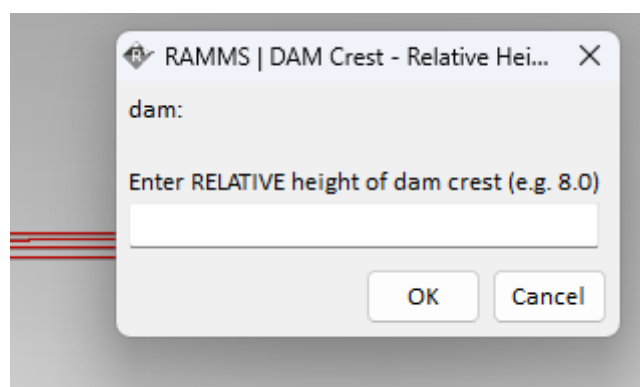


Figure 5-70: Specification of dam crest elevation with the relative height from footprint file.

After inputting the geometry information, the user is requested to enter the dam failure energy, and the dam face M_E properties.

5.10.2 Rockfall Sheds

Rockfall sheds are treated in **RAMMS::Rockfall** in a manner analogous to dams. They are represented as rigid obstacles defined by a convex hull (point-cloud geometry) and interact with falling rocks by intercepting, deflecting, or stopping their motion depending on the impact conditions.

The standard workflow for creating rockfall sheds in RAMMS is optimized for structures with a **horizontal roof surface**, which reflects the most common shed configuration. This allows sheds to be generated efficiently using the built-in input tools. Alternatively, a rockfall shed can be defined externally by creating a point-cloud (*.pts) file and importing it directly into RAMMS. This approach is particularly useful for complex geometries or for reproducing existing structures.

Details on the required point-cloud format and accompanying files are provided in the Section: 5.8.2 *Format of Point-Cloud Object*.

Creating a (horizontal) gallery object in RAMMS

The following procedure outlines how to create a gallery object in RAMMS. Since the shed roof must be **horizontal** (for now), it is recommended to use a contour plot for reference. The contour lines will help you define the basic shapefile—particularly the mountain-side boundary, as shown in the images below.

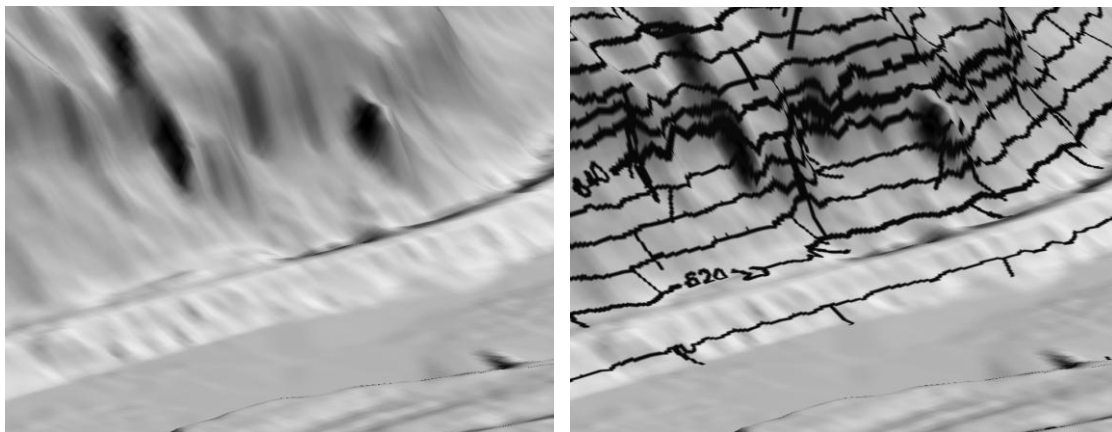


Figure 5-71: Planned rockfall shed with (right) and without (left) contour lines.

Step 1: Draw the Rockfall Shed Footprint

1. Switch to **2D mode**.
2. Draw the **footprint** of the planned shed object using a new **polygon shapefile**.
3. Use the **contour line** (in this case 625m) as the boundary on the hillside (see Figure 5-71).

Step 2: Create the Shed Object

1. Navigate to **Input → Sheds... → Create Shed (Elevation)**. The procedure is similar to the specification of dams.
2. Select the **footprint shapefile**. This shapefile represents the **shed roof**.
3. Enter the name of the shed.
4. When prompted for the **elevation**, enter the hillside elevation (625m in this example).
5. Input **energy absorption capacity** and **ME-value** (refer to the dam section above for details).
6. *RAMMS::Rockfall* will then generate and display the gallery object (see Figure 5-72).

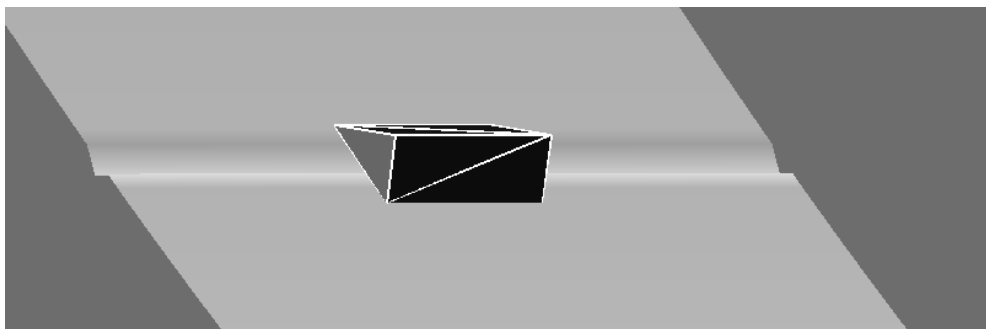


Figure 5-72: Visualization of a rockfall shed over a road cut.

Additional Notes:

- If the shed is visualized as a **black object**, they will always be considered in a new simulation.
- To exclude objects from a simulation, remove all objects via **Input → Remove Barriers/Dams/Sheds**.
- Once the user has defined a shed name (a *.pts), the corresponding *.pts file can be re-introduced into the simulation by using **Input → Sheds... → Add Existing Sheds**.
- This procedure can be used to quickly redefine the **energy absorption capacity** and the **ME-value** without re-making the shed geometry
- Select **multiple .pts files** (by holding the Shift key) to assign the same parameters to multiple objects.

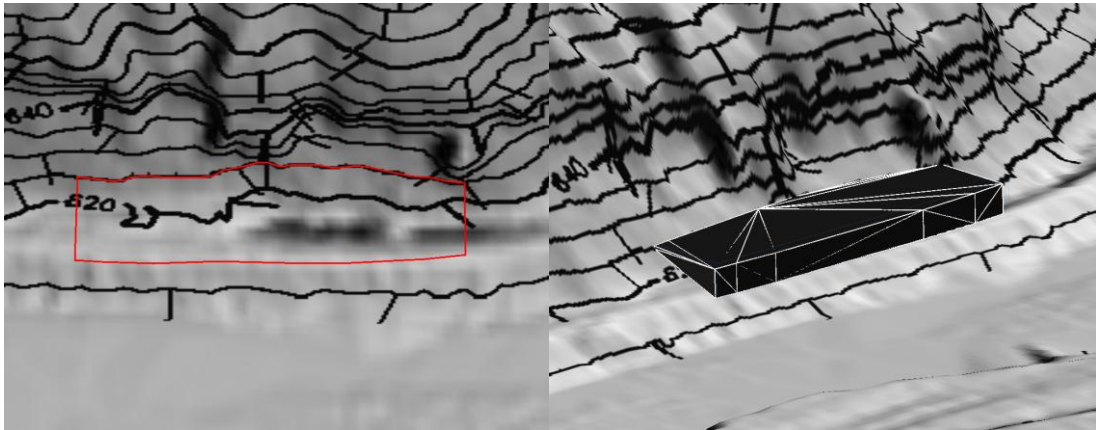


Figure 5-73: Footprint of planned gallery object (left) and gallery-point-cloud-object (right). Note that the shed roof follows the contour line with multiple points.

5.10.3 Format of point-cloud-object (Dam or Shed)

An obstacle point-cloud object consists of two files:

- **<gallery_name>.pts**: Point-cloud coordinates (x, y, z), relative to the reference point. Any point of the point-cloud-points can be the reference point.
- **<gallery_name>.txt**: Coordinates of reference point (x, y, z), in cartesian coordinate system.
- **With this information, object point-cloud files can also be created outside of RAMMS.**

Gallery_625_0.pts			
1	0.00000000	0.00000000	0.00000000
2	2.5088603	-0.25088345	-1.3889771
3	3.8887340	-0.50176686	0.47198486
4	5.8958223	-0.62721460	-1.2570190
5	7.2756960	-0.87809802	-1.2570190
6	9.4082268	-0.87809808	-1.1119995
7	10.913543	-0.75265643	-1.0570068

Gallery_625_0.txt			
1	2744897.5	1185775.6	625.63800
2			

Figure 5-74: Point-cloud file (.pts) and reference point file (.txt)

5.10.4 Structural Impact Parameters for Rocks and Sheds

Once a dam or shed object has been created, its mechanical interaction with impacting rocks during the simulation is governed by two structural impact parameters:

- **Energy Absorption Capacity** (failure energy)
- **Compression Modulus** (ME)

These parameters control both the *survival* of the structure during impact and the *magnitude of energy dissipation* that occurs.

Energy Absorption Capacity (in kJ)

When a rock impacts a dam or shed, the model first evaluates whether the structure remains intact. Let E_{impact} denote the kinetic energy of the rock at the moment of impact.

If $E_{impact} > E_{abs}$ where E_{abs} is the **Energy Absorption Capacity**, the structure is assumed to fail instantaneously.

In this case:

- **The dam or shed is considered destroyed.**
- **No energy dissipation occurs.**
- **The rock continues its downward trajectory with its full impact energy.**

If $E_{impact} \leq E_{abs}$ the structure remains intact and energy dissipation is activated through the resistance formulation described below.

This binary check ensures that structural failure and intact behavior are clearly separated in the simulation. The energy absorption E_{abs} is input when specify an object (see Figure 5-75)

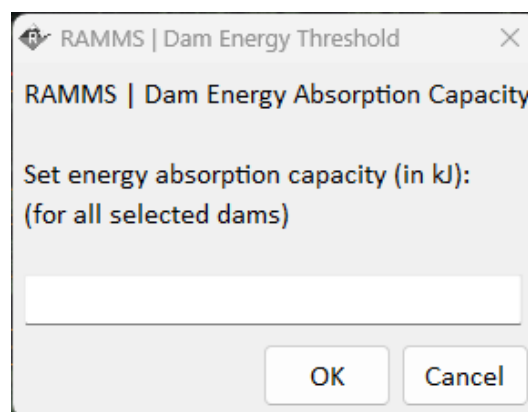


Figure 5-75: Set energy absorption capacity of the dam (in kilojoules, kJ)

Compression Modulus (M_E , in MN/m²)

If the structure survives the impact, dissipation is controlled by the **Compression Modulus (M_E)**. The ME parameter defines an empirical **dissipation factor**:

$$f = 80 \cdot e^{-4 \times 10^5 M_E}$$

with: M_E in kN/m². Because of the negative exponent, **smaller ME values produce larger values of f** , resulting in stronger dynamic hardening and greater resistance growth during penetration. Conversely, larger M_E values lead to smaller f , reducing the hardening effect.

The factor f represents a multiplicative growth factor applied to the resistance force factor C_d . It simulates strain hardening as the dam material compacts under high-speed impact.

For both dams and sheds the M_E factor is given in the input menu during creation (see Figure 5-76)

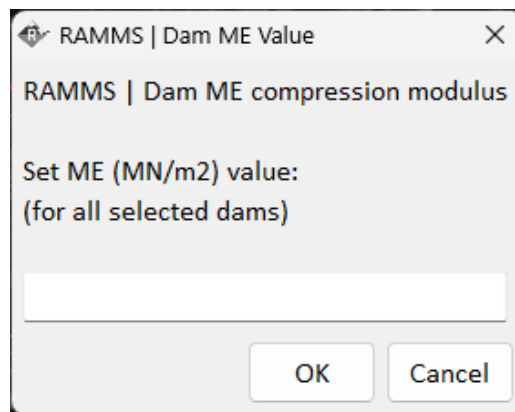


Figure 5-76: Set ME value (in MN/m²)

During impact, a retarding force opposes the motion of the rock. In **RAMMS::Rockfall**, this resistance force is computed using a resistance force factor C_d .

The initial value of C_d is defined as:

$$C_d = \frac{f \cdot M}{d \cdot A \cdot \rho}$$

where:

- M = mass of the rock
- d = penetration depth
- A = impact area
- ρ = density of dam material (assumed $\rho = 2000 \text{ kg/m}^3$)
- f = dissipation factor defined above

The resistance force acting on the rock is then computed as:

$$F_{res} = C_d \cdot v^2$$

where v is the instantaneous impact velocity.

Implications:

- Higher impact velocities produce larger resistance forces (quadratic dependence).
- For a given velocity:
 - Larger rock mass → higher resistance force.
 - Larger impact area → lower resistance force.
 - Smaller impact area → higher resistance force due to stress concentration.

Penetration Depth (d)

Estimated empirically as:

$$d = 0.1 \cdot (M_E)^{-0.4} \cdot M^{1/3} \cdot \left(\sqrt{v_x^2 + v_y^2} \right)^{0.8}$$

where:

- M_E : Compression modulus
- v_x, v_y : x and y components of rock velocity

Area of Impact (A)

The area of impact, A , is estimated using a characteristic length scale, L , derived from the rock mass. The characteristic length is defined as:

$$L = 0.5 \cdot \left(\frac{M}{2500} \right)^{1/3}$$

where M is the mass of the rock (in kg). This formulation assumes a simplified cubic representation of the rock and provides a representative length scale for impact calculations.

The area of impact is then computed as:

$$A = L^2$$

This simplified approach yields an effective contact area that is used in the calculation of the resistance force factor C_d . The characteristic length L is **not** intended to represent the penetration depth; rather, it serves solely as a geometric scaling parameter based on rock mass.

It should be noted that this formulation is a simplification of the true rock–dam contact mechanics. In the current implementation, the impact area does not account for the actual rock geometry or its orientation at impact. Future versions of **RAMMS::Rockfall** will refine this approach by incorporating contact areas derived directly from the rock shape and impact configuration.

Rock Arrest and Sticking Behaviour

If the dissipative forces remove all kinetic energy from the rock before it exits the structure surface, the rock comes to rest.

In such cases:

- Rocks may become lodged on a dam face.
- Rocks may remain on a rockfall shed roof.
- The simulation captures full arrest when kinetic energy is reduced to zero.

This mechanism allows realistic representation of both:

- Complete structural failure (no dissipation), and
- Successful energy absorption with possible rock retention.

See Figure 5-77.

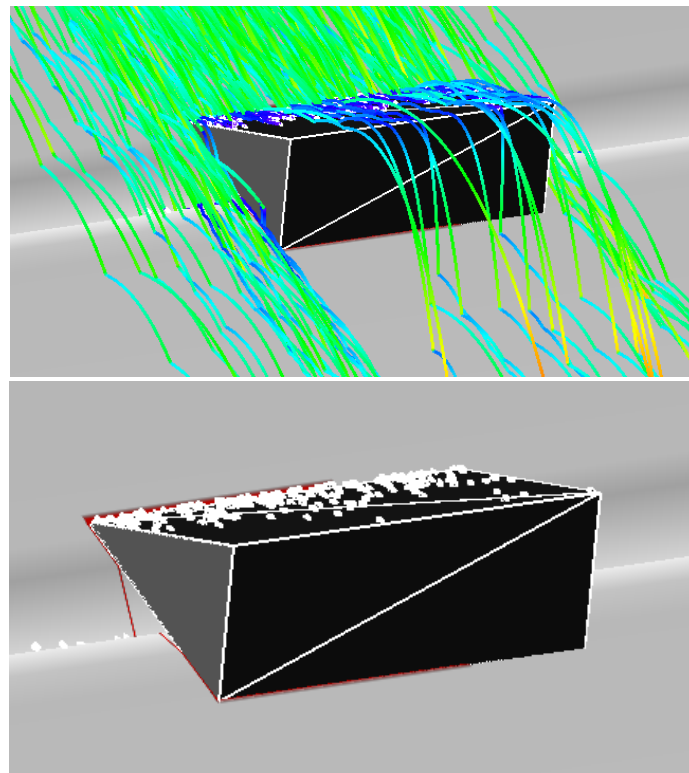


Figure 5-77: (Top) Rocks moving over a rockfall shed roof. Note that the rocks plunge over the backside of the shed and are re-accelerated. (Bottom) Most rocks are stopped on the rockfall roof.

Section 7.5.1 on page 205 explains how to analyze gallery impacts.

6 Simulation Setup and Execution

Rockfall simulations in RAMMS are initiated through the **Run Simulation** window, which is accessed by activating the *Run Simulation* icon in the main interface. This window serves as the central control panel for defining all model inputs and execution parameters.



The interface is organized into seven tabs—**General**, **Terrain**, **Forest**, **Dam/Net**, **Rock**, **Release**, and **Stop**—each representing a key component of the simulation setup (Figure 6-1). Together, these tabs guide the user through the complete workflow required to define terrain characteristics, release conditions, interaction processes, and stopping criteria.

All tabs must be configured appropriately before a simulation can be executed. The following sections describe each tab in detail and explain the parameters required to perform a complete and consistent rockfall simulation.



Figure 6-1: Run Simulation window in RAMMS::Rockfall showing the seven tabs (General, Terrain, Forest, Dam/Net, Rock, Release, and Stop) used to define and execute a rockfall simulation.

6.1 Seven Tabs

6.1.1 General Tab

The **General** tab comprises five key settings that define the basic configuration of the simulation:

- **Scenario Name** – Specifies the name of the simulation and associated output files.
- **Dump Step (s)** – Controls how frequently simulation results are written to the output.
- **Digital Elevation Model (DEM)** – Defines the terrain model used for the simulation (*.xyz file). If you add a dam or shed to the DEM, a new xyz-file is written, and you can choose the xyz-file here. If you change the xyz-file,

the new terrain model is used for the simulation, but the actual terrain model is not updated.

- **Calculation Domain (optional)** – Allows restriction of the simulation area using a polygon shapefile.
- **Number of Threads for Parallel Simulation** – Determines how the computational workload is distributed across available CPU resources.
- **Save FULL Output** – Controls whether all output variables or only a reduced set are stored.

RAMMS | Run Simulation

General Terrain Forest Dam/Net Rock Release Stop

GENERAL SIMULATION PARAMETERS

SCENARIO Name

Sim_Dam_Example

Time Integration

Dump Step (s): 0.0200

DEM & Domain Stuff

Digital Elevation Model Information

DEM File: SimulationsShed.xyz

Use calculation domain (shapefile, optional)

Shapefile:

Nr Threads for Parallel Simulation

To ensure optimal performance, the number of threads should evenly divide
- 60 random orientations

Suggested Thread Counts: 20 Or enter your own:

[OK] 20 threads divide 60 random orientations -> Good choice.

☒ Save FULL Output

Cancel

RUN ~300~ SIMULATIONS

Figure 6-2: Run Simulation window – General tab. The tab contains the basic simulation settings, including scenario name, output frequency, terrain input, optional calculation domain, and the number of threads used for parallel computation.

Scenario Name

The **Scenario Name** defines the basic name of the simulation case and its associated output files. A specific and descriptive scenario name should be entered so that simulation results can be clearly identified and distinguished from other model runs.

It is recommended to use names that reflect the main characteristics of the scenario, such as release area, terrain configuration, or parameter variation.

Time Integration

The **Dump Step (s)** controls how frequently simulation results are written to the output files. In the default setting, RAMMS uses a value of **0.0200 s**.

The dump step is larger than the internal numerical time step and determines the temporal resolution of the saved output rather than the resolution of the numerical calculation itself. For example, reducing the dump step leads to more frequent output storage and therefore a more detailed record of the simulated motion, but it also increases file size. Increasing the dump step reduces storage requirements but saves results at a lower temporal resolution.

The user may adjust this value depending on the desired level of detail in the output and the available storage capacity.

DEM and Domain Settings

The **Digital Elevation Model Information** indicates which DEM file is currently used for the simulation. This terrain model forms the basis for all rockfall calculations and defines the topographic surface on which rock trajectories are simulated.

Under **Use calculation domain (shapefile, optional)**, a polygon shapefile may be specified to restrict the simulation to a defined area within the DEM. This option is useful when only a subset of the terrain should be considered, for example to reduce the calculation area to the relevant slope section or study perimeter.

If no shapefile is provided, the full DEM extent is used for the simulation.

Number of Threads for Parallel Simulation

RAMMS performs rockfall simulations in parallel to reduce computation time. The **Nr Threads for Parallel Simulation** setting allows the user to define how many threads are used for the calculation.

For efficient performance, the selected number of threads should divide the number of independent simulation tasks. In **RAMMS::Rockfall**, the workload is distributed according to either the number of release points or the number of random orientations, depending on which of these is larger. For this reason, RAMMS suggests thread counts that divide this governing number evenly.

In the example shown in Figure 6-3, the simulation uses **5 starting points** and **60 random orientations**, and **20 threads** are suggested because 20 divides 60 without

remainder. This leads to a balanced distribution of the computational workload and therefore to better performance.

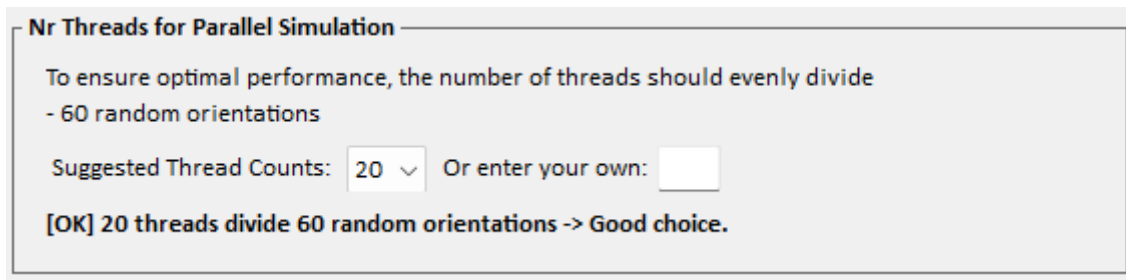


Figure 6-3: Example of workload distribution in a RAMMS::Rockfall simulation with 5 release points and 60 random orientations, resulting in 300 trajectories. The simulation is executed using 20 threads, which evenly divide the number of random orientations to ensure efficient parallel computation.

If a manually defined thread count does not divide the governing number evenly, the remaining tasks are assigned to the last thread. This may reduce computational efficiency and increase total run time.

In general, using more threads reduces simulation time. However, assigning all available threads may limit the computer's responsiveness for other parallel activities. In cases with very large forest datasets, performance may not always improve with the maximum possible number of threads, because reading large input files can become an additional bottleneck.

Save FULL Output

At the bottom of the window, the option **Save FULL Output** determines the amount of simulation data written to file.

When this option is activated, all available output variables are saved. This provides the most complete record of the simulation but increases storage requirements. If the option is not selected, RAMMS stores only a reduced set of standard output variables. The reduced output is generally sufficient for many routine analyses and helps to limit file size.

The choice depends on the purpose of the simulation. Full output is recommended when detailed post-processing or advanced analysis is required.

6.1.2 Terrain Tab

The **Terrain tab** (Figure 6-4) defines the mechanical properties of the ground surface used in the rockfall simulation. These properties control how rocks interact with the terrain, including impact behavior, energy dissipation, and runout distance.

The terrain is defined using a combination of a **background terrain category** and **spatially distributed terrain types** assigned via shapefiles.

Overall Terrain Parameters

The **Terrain category** in the upper section defines the default ground type for all areas where no shapefile-based terrain classification is applied. This ensures that the entire simulation domain is assigned valid ground properties.

The user may select a predefined terrain type from the dropdown list or manually define the parameters:

- **ME (MN/m²): Compression modulus**, controlling ground stiffness and rebound behavior.
- **Cd (–): Drag coefficient**, controlling energy loss during rock–ground interaction.

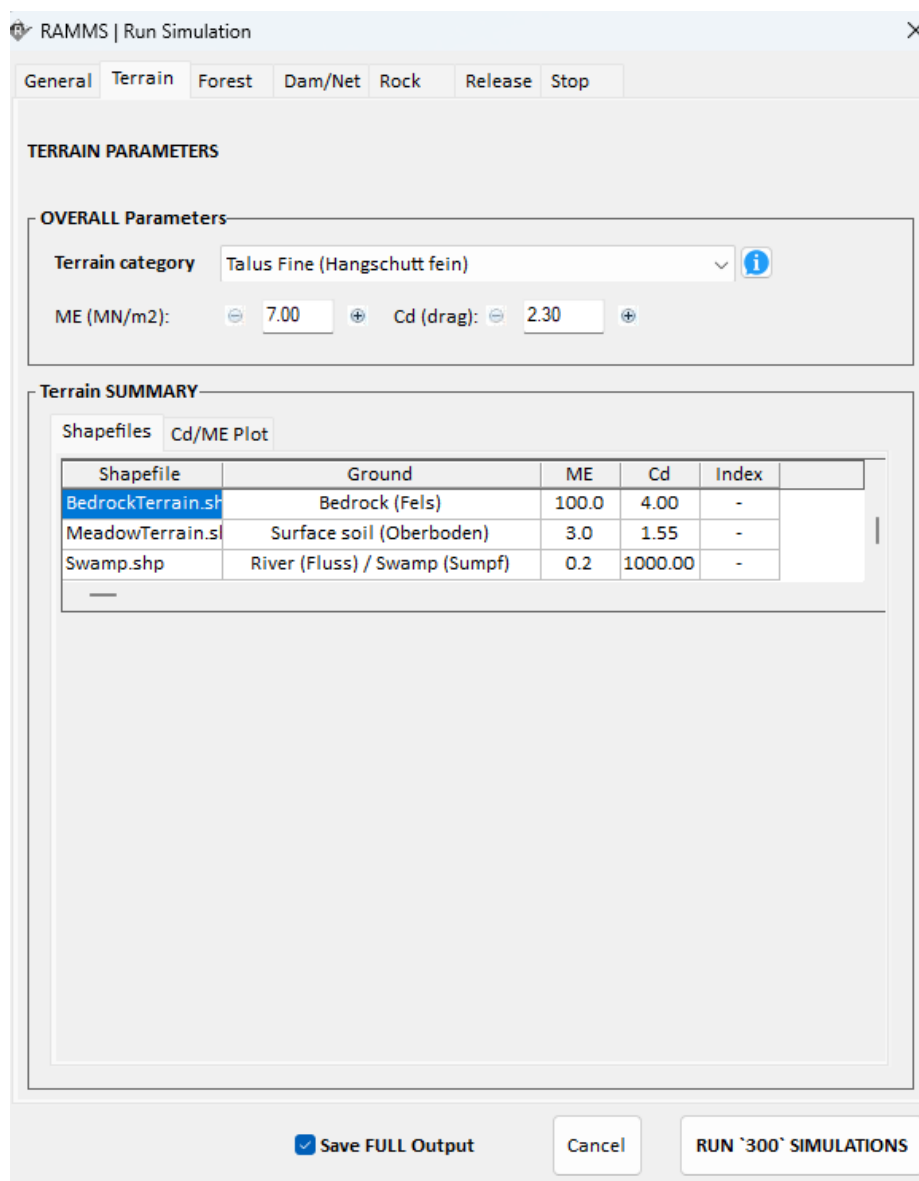


Figure 6-4: Run Simulation window – Terrain tab.

The available default terrain categories include:

- **Surface Soil**
- **Subsoil**
- **Alpine Spruce/Beech Forest**
- **Talus Vegetated**
- **Talus Fine**
- **Talus Coarse**
- **Talus Blocs**
- **Boulder Field**
- **Mountain Road**
- **Asphalt**
- **Bedrock**
- **River / Swamp**
- **Snow**

These predefined categories represent typical ground conditions and are described in detail in the corresponding parameter tables (see Table 4.3 and Table 4.4).

Terrain Summary (Shapefile-Based Definition)

The lower section of the tab provides a **Terrain Summary**, listing all shapefiles that have been assigned terrain categories. Each shapefile represents a spatially defined area with specific ground properties.

Terrain types are assigned to shapefiles externally in the project workspace (e.g., by right-clicking a shapefile and selecting *Set Soil*). Once assigned, they appear in this list along with their corresponding:

- **Ground type**
- **ME value**
- **Cd value**

This allows the user to verify that all relevant terrain units are correctly defined and included in the simulation.

It is important to ensure that all intended shapefiles are present in the list; otherwise, they will not be considered during the simulation.

Order of Shapefiles

When multiple shapefiles overlap, the **order of specification in the Terrain Summary is critical**. The last shapefile in the list takes precedence and overrides previously defined terrain categories in overlapping areas.

Careful ordering of shapefiles is therefore required to ensure that the correct terrain properties are applied.

Cd/ME Plot

The **Cd/ME Plot** tab provides a graphical representation of the assigned terrain categories and their associated mechanical parameters (Figure 6-5). This visualization can be used to compare ground types and verify consistency across the model.

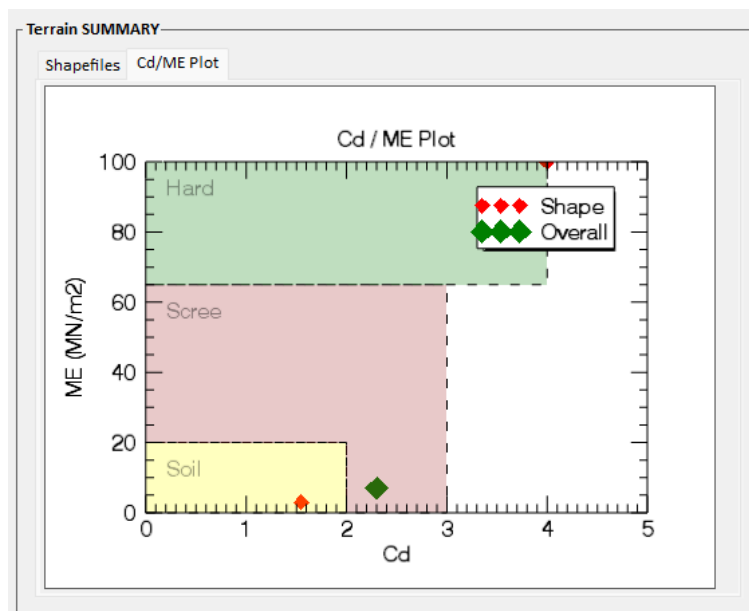


Figure 6-5: Cd/ME plot showing the relationship between the drag coefficient (Cd) and compression modulus (ME) for the terrain categories used in the simulation. The plot provides a graphical comparison of ground types and their associated mechanical properties.

Save FULL Output

As in other tabs, the **Save FULL Output** option is available at the bottom of the window. When activated, all simulation output variables are stored; otherwise, only a reduced set of standard outputs is saved

6.1.3 Forest Tab

The **Forest tab** (Figure 6-6) provides a summary of all forest areas included in the simulation and their associated parameters. Forests can significantly influence rockfall behavior by reducing velocities, altering trajectories, and limiting runout distances through impacts with trees.

In **RAMMS::Rockfall**, forests are defined spatially using polygon shapefiles and must be assigned prior to running a simulation.

Forest Definition

To include forested areas in a simulation, the user must first create or import polygon shapefiles representing forest regions. Forest parameters are then assigned to these shapefiles using the **Set Forest** command (e.g., by right-clicking the shapefile in the file tree or by using the *Edit Forest Parameters* tool for individual polygons).

Each shapefile can be assigned either:

- a predefined forest type, or
- user-defined parameters such as tree density and diameter distribution.

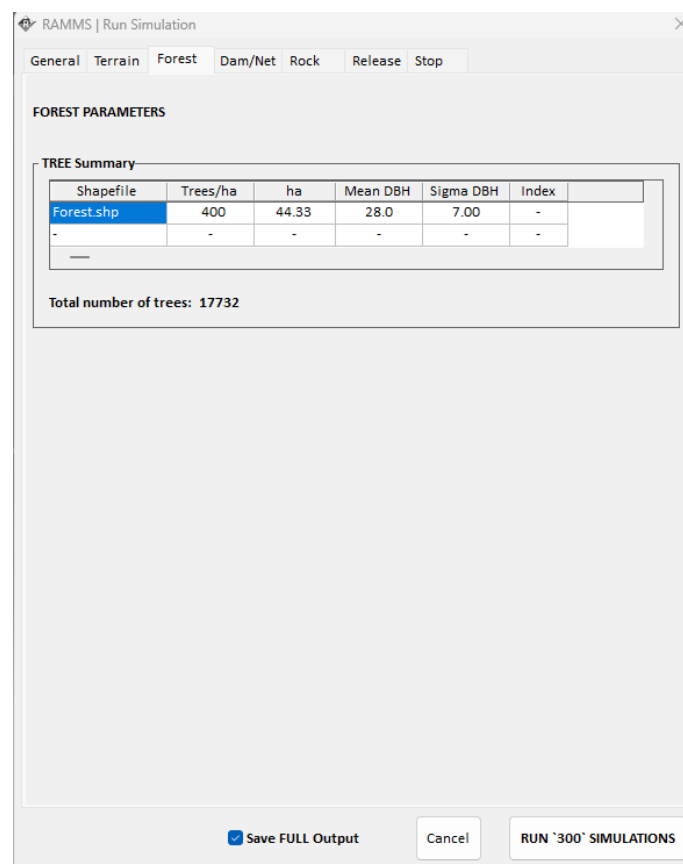


Figure 6-6: Run Simulation window – Forest tab. The table summarizes all forest shapefiles included in the simulation, including tree density, area, diameter distribution (DBH), and the total number of generated trees.

Tree Summary

The **Tree Summary** table lists all shapefiles that have been assigned forest properties. For each shapefile, the following parameters are displayed:

- Trees/ha – Tree density within the shapefile
- ha – Area of the shapefile
- Mean DBH – Mean diameter at breast height of the trees
- Sigma DBH – Standard deviation of the DBH distribution
- Index – Identifier for the assigned forest type

Based on these parameters, RAMMS generates a synthetic forest for each shapefile, which is used during the simulation to model rock–tree interactions.

Total Number of Trees

The total number of generated trees across all forest shapefiles is displayed at the bottom of the tab. This value reflects the cumulative forest density in the simulation and provides an indication of the computational complexity of forest interactions.

Important Notes

- The **Forest** tab is **informational**; forest parameters are defined outside this tab through the shapefile and forest assignment workflow.
- Ensure that all intended forest shapefiles are listed in the summary; otherwise, they will not be included in the simulation.
- Forest regions should **not overlap**, as overlapping shapefiles will result in tree densities being added together, potentially producing unrealistic forest conditions.
- Assigning a forest to a shapefile does **not automatically** define the ground (terrain) properties for that area. Terrain types must be assigned separately in the **Terrain** tab.

Save FULL Output

As in other tabs, the **Save FULL Output** option is available at the bottom of the window and controls whether all output variables or only a reduced set are stored.

6.1.4 Dam/Net Tab

The **Dam/Net tab** (Figure 6-7) is used to include rockfall mitigation structures such as rockfall dams, sheds, and nets in the simulation. These structures are represented as three-dimensional objects that can intercept, deflect, or stop falling rocks depending on their geometry and energy absorption capacity.

All defined objects are listed in this tab and can be reviewed, added, or removed prior to running the simulation.

Object List

The main table displays all dams, sheds, or net structures currently included in the simulation. For each object, relevant properties such as the geometry file, object type, and energy-related parameters are listed.

Objects can be managed directly within this list:

- **Delete** – Removes the selected object from the simulation
- **Clear List** – Removes all objects from the simulation

This allows the user to quickly modify or reset the set of mitigation measures included in the model.

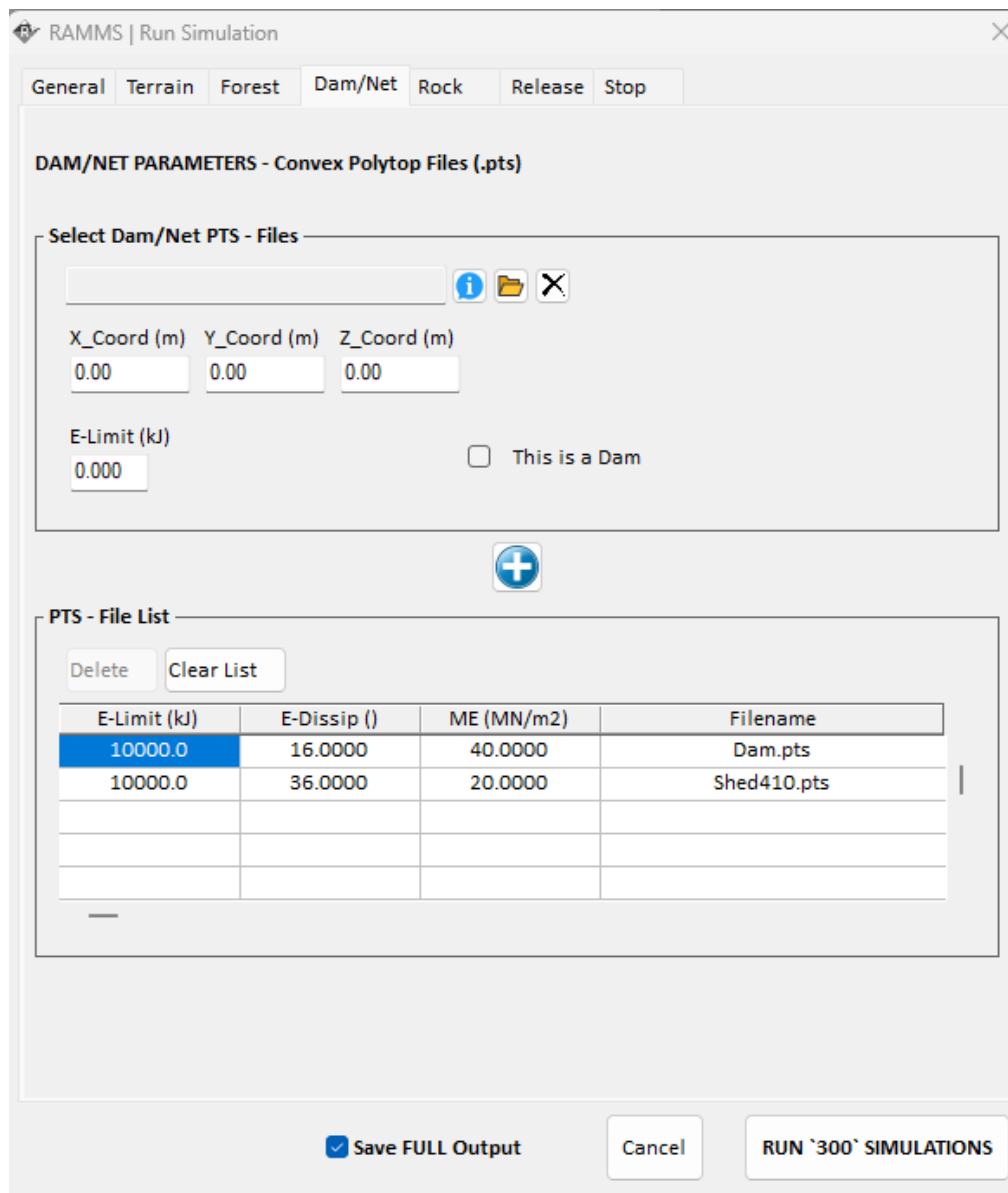


Figure 6-7: Run Simulation window – Dam/Net tab. The table lists all mitigation structures (dams, sheds, or nets) included in the simulation, along with their geometry files and structural parameters such as energy threshold, ME, and Cd.

Adding Dam/Net Objects

Mitigation structures are typically defined in advance (see sections 5.9 and 5.10) and stored as point-cloud files (*.pts), which represent the three-dimensional geometry of the object.

To include an object in the simulation:

1. Select **Add Dam/Net pts-file**
2. Choose the corresponding *.pts file (and associated reference file)
3. Assign the required structural parameters
4. Click the **+** (**Plus**) button to add the object to the list

Multiple objects can be added and combined within a single simulation.

Object Type and Parameters

When adding an object, the user must specify whether it is a **dam (or shed)** or a **net**, as this determines how the structure interacts with falling rocks.

• Dams and Sheds

- Represent rigid, three-dimensional obstacles embedded in the terrain
- Require specification of:
 - Energy threshold (kJ) – Maximum kinetic energy the structure can absorb
 - ME (MN/m²) – Compression modulus
 - Cd (–) – Energy dissipation parameter

• Nets

- Represent flexible barriers
- Require only the energy threshold, as ME is not used for nets

If the kinetic energy of an impacting rock exceeds the specified energy threshold, the structure is considered to have lost its effectiveness. The impact is still recorded, but the rock continues its motion without further interaction with the object.

Notes on Object Definition

- **Dams and sheds must be defined prior to being added in this tab (for example via Input → Dams... or Input → Sheds...).**
- **The geometry is stored in *.pts files and can be reused across simulations.**
- **Multiple mitigation structures can be included in a single model domain.**
- **All objects shown in the list are active in the simulation unless removed.**

Save FULL Output

As in other tabs, the **Save FULL Output** option is available at the bottom of the window and controls whether all output variables or only a reduced set are stored.

6.1.5 Rock Tab

The **Rock tab** (Figure 6-8) defines the **geometry, size, and physical properties of the falling rocks** used in the simulation. Rock shape is a critical input parameter, as it directly controls impact behaviour, rotation, and energy dissipation during rockfall motion.

Within the RAMMS workflow, the Rock tab corresponds to the step “**Define Rock Properties**”, where rock geometry is specified prior to running simulations.

Rocks in RAMMS are represented as **rigid bodies with convex polyhedral geometry derived from point clouds**, allowing realistic simulation of impacts and rotational motion.

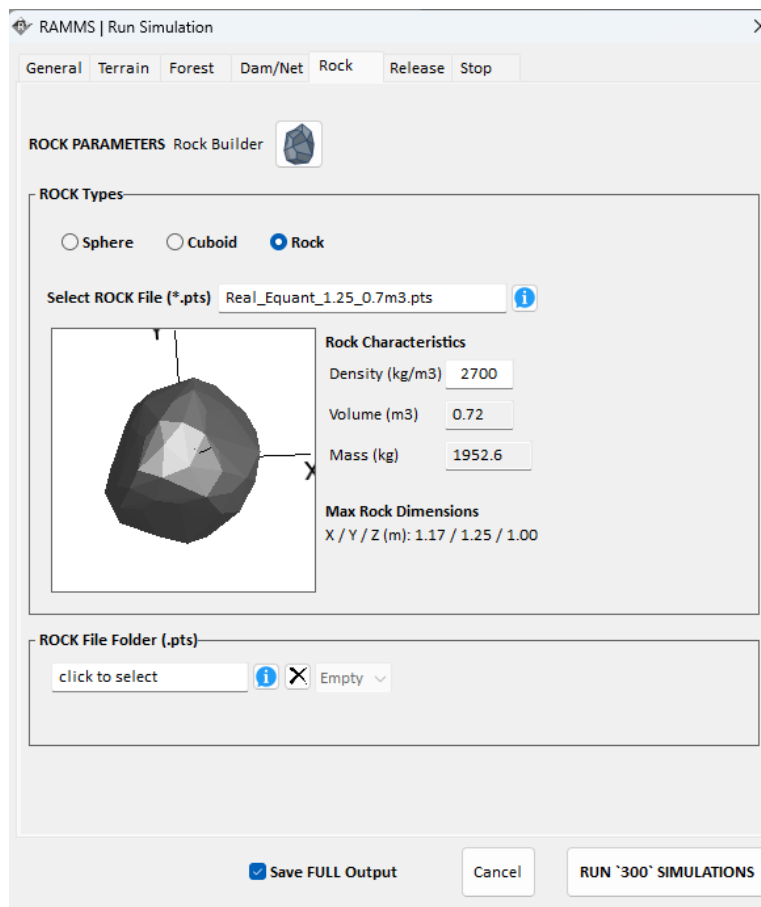
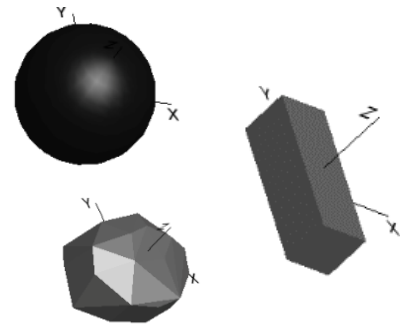


Figure 6-8: Run Simulation window – Rock tab. The tab allows selection of rock type (sphere, cuboid, or realistic rock), loading of rock geometry files (*.pts), visualization of the selected rock, and definition of physical properties such as density, volume, and mass. Multiple rock geometries can be assigned using a folder of *.pts files.

Rock Types

Three types of rocks can be defined:

- Sphere – Artificial rock defined by a radius
- Cuboid – Artificial rock defined by dimensions in X, Y, and Z
- Rock – Realistic rock geometry defined using the Rock Builder (.pts file)



Recommended Approach

Although spherical and cuboid rocks are available for testing and simplified analyses, they are **not recommended for realistic rockfall simulations**.

Rockfall motion is governed by rigid-body dynamics with intermittent impacts. The **location of the contact point relative to the center of mass generates torque**, which controls rotation and trajectory evolution.

Because rock shape determines the position of this contact point:

- Irregular rocks generate realistic rotational motion
- Impact behaviour varies depending on contact geometry
- Trajectory variability increases significantly

Spherical rocks are symmetric and therefore:

- produce minimal rotational variability
- tend to roll unrealistically on slopes
- often lead to excessive runout distances

Cuboids improve rotational behaviour but still do not capture the complexity of natural rock shapes.

For realistic simulations, it is therefore **strongly recommended to use convex polyhedral rock geometries** generated with the Rock Builder.

Real Rocks (.pts Files)

When selecting **Rock**, the geometry is defined using a point-cloud file (*.pts) created with the Rock Builder.

Selecting a Rock

- Use Select ROCK File (*.pts) to load a predefined rock
- A 3D visualization of the rock is displayed in the window
- The rock can be rotated interactively using the mouse

The following properties are displayed:

- Density (kg/m³)
- Volume (m³)
- Mass (kg)
- Maximum dimensions (X / Y / Z)

Important Note on Density and Mass

The *.pts file stores **only the rock geometry (vertices)**.

Mass and density values are not stored and must be defined in the simulation.

This means:

- Geometry → defined in Rock Builder
- Density → defined in the Rock tab
- Mass → computed automatically

Rock Folder (Multiple Rocks)

Instead of a single rock, a folder containing multiple *.pts files can be selected.

- All rocks in the folder are used in the simulation
- Each rock represents a different geometry (and potentially size)
- The total number of simulations increases accordingly

This approach is useful for:

- representing natural variability in rock shapes
- performing ensemble simulations
- improving statistical robustness

Rock Builder

The **Rock Builder** (Figure 6-9) is the primary tool for generating realistic rock geometries.

It can be launched directly from the Rock tab or from the main interface.

Rocks in RAMMS are represented as **convex hull geometries derived from point clouds**, which are used to compute impacts and rotations during simulation.

The Rock Builder allows the user to:

- create or import rock shapes
- define volume, dimensions, and density
- generate reusable rock libraries
- export rock geometries as *.pts files

In practice:

- real rocks can be approximated using predefined shapes
- or generated from scanned point clouds (e.g. photogrammetry)

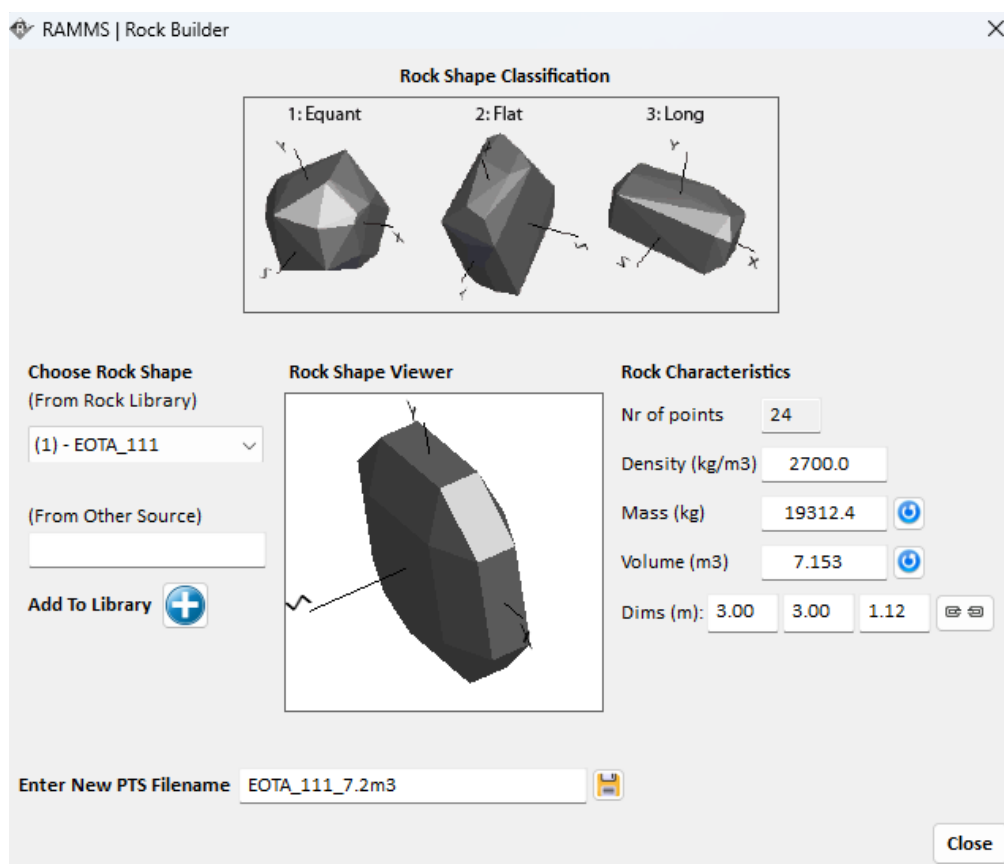


Figure 6-9: Rock Builder interface. The tool is used to create realistic rock geometries based on convex hull point clouds. Users can define rock shape, volume, density, and dimensions, visualize the geometry interactively, and export the rock as a *.pts file for use in simulations.

Practical Recommendations

- Use realistic rock geometries (.pts files) whenever possible
- Avoid spheres except for testing purposes
- Use cuboids only for simplified sensitivity studies

- Use multiple rocks (folder option) to represent natural variability
- Ensure rock size and volume are consistent with field observations

6.1.6 Release Tab

The **Release** tab defines the initial conditions of the rockfall simulation beyond the spatial release locations. While release points, lines, or areas determine *where* rocks start, this tab controls *how* they start, including their orientation, initial motion, and initial position relative to the terrain.

RAMMS | Run Simulation

General Terrain Forest Dam/Net Rock Release Stop

RELEASE PARAMETERS

RELEASE Orientations

Nr of Random Orientations 60 ?

☐ Use existing random orientations

RELEASE Summary

Shapefile	Nr Verts	Type	Index
ReleasePoints	5	point	-
Total	5	-	-

Initial Velocities (optional)

Initial Velocity (X,Y,Z) (m/s) 0.00 0.00 0.00

Initial Rot. Velocity (X,Y,Z) (rad/s) 0.00 0.00 0.00

ROCK Z-Offset

☒ Automatic ☐ Manual

☒ Save FULL Output Cancel RUN `300` SIMULATIONS

Figure 6-10: Run Simulation window – Release tab. The tab defines the initial conditions of the simulation, including the number of random orientations, summary of release points, optional initial velocities and rotations, and the rock Z-offset controlling the initial release position.

The tab is divided into four main sections: **Random Orientations**, **Release Summary**, **Initial Velocities**, and **Rock Z-Offset**.

The total number of simulated trajectories is determined by the combination of:

- **number of release points**
- **number of rock shapes**
- **number of random orientations**
- **number of Z-offset steps (if applicable)**

This total is displayed in the **RUN “XXX” SIMULATIONS** button.

Random Orientations

The **Nr of Random Orientations** defines how many different initial orientations are assigned to each rock at every release location.

Because rocks have irregular shapes, their orientation at first contact strongly influences impact behavior and trajectory evolution. By randomly rotating the rock multiple times, RAMMS generates a statistical distribution of possible trajectories.

For example:

- 5 release points and 60 random orientations result in 300 simulated trajectories

Increasing the number of random orientations improves the statistical reliability of the results, particularly for hazard assessment and intensity mapping.

Recommended workflow:

- Perform initial test runs with a low number of orientations (e.g. 10–15)
- Increase to 20–30 orientations or more for final simulations
- Continue increasing until key output metrics (e.g. energy or impact probability at a target area) stabilize

Very low values (e.g. less than 5) should be avoided, as they do not capture the variability of rockfall behavior.

The option **Use existing random orientations** allows reuse of previously generated orientations for reproducibility between simulations.

The initial orientation **primarily influences the first impact**, which often determines whether the rock continues bouncing, rolling, or comes to rest.

Release Summary

The **Release Summary** provides an overview of all active release shapefiles and the number of release points used in the simulation.

Release zones are defined externally by assigning shapefiles (points, lines, or polygons) as release areas. Depending on the type:

- **Points** define fixed starting locations
- **Lines** distribute release points along a line
- **Polygons** generate randomly distributed release points within an area based on the specified number of release points.

The summary table lists:

- shapefile name
- number of vertices or release points
- type of release geometry

It is important to verify that all intended release zones are included in this list, as only listed shapefiles are used in the simulation.

Initial Velocities (optional)

The **Initial Velocities** section allows the user to define translational and rotational motion of the rock at the moment of release.

- **Initial Velocity (X, Y, Z) [m/s]** – Defines the initial translational velocity in the three global coordinate directions
- **Initial Rotational Velocity (X, Y, Z) [rad/s]** – Defines the initial rotation around the three local rock axes

These parameters are optional and are typically set to zero for standard rockfall simulations.

However, they can be useful in specific cases, such as:

- simulating rocks that are already in motion at release
- initiating impacts on structures (e.g. dams or sheds)
- modelling special scenarios such as volcanic or explosive rock ejections

In most applications, the default values (zero velocity and rotation) are appropriate.

Rock Z-Offset

The **Rock Z-Offset** defines the initial vertical position of the rock relative to the terrain surface. It ensures that the rock **does not intersect the terrain at initialization** and that contact forces are computed correctly from the first time step.

Two modes are available:

- **Automatic (default)**

RAMMS automatically positions the rock slightly above the terrain surface along the slope-normal direction. This ensures that the rock does not intersect the terrain at the start of the simulation and can begin moving correctly. This is the recommended setting for most applications.

- **Manual**

The user specifies a vertical offset (in meters) measured from the center of mass of the rock. This effectively increases the initial potential energy and can be used to simulate release from a height above the terrain.



Figure 6-11: Definition of rock Z-offset in RAMMS::Rockfall. In automatic mode, the rock is positioned normal to the terrain surface to avoid initial intersection with the DEM. In manual mode, the rock is vertically offset from its center of mass, increasing its initial potential energy and influencing the impact energy and trajectory evolution.

This option is useful for representing release from steep rock faces or cliffs and will increase the total number of simulations accordingly.

When **Manual** Z-offset is selected, the user must define the initial vertical position of the rock relative to the release location. The offset is measured from the **center of mass of the rock** and specifies the height above the terrain at which the rock is initialized.

The **Use Multi** option allows multiple release heights to be defined at each release location. This is particularly useful for representing rock release from steep cliffs or extended rock faces, where detachment may occur at different elevations.

The following parameters must be specified:

- **Rock Z-Offset (m)** – Initial offset (starting height) of the rock above the terrain
- **Delta (m)** – Vertical increment between successive release heights
- **Steps** – Number of increments applied

RAMMS generates multiple release positions by successively increasing the initial offset using the defined delta and number of steps. This results in several rocks being released at different heights from the same horizontal location.



The screenshot shows a software interface for configuring rock release parameters. It features a title bar 'ROCK Z-Offset'. Below it are two radio buttons: 'Automatic' (unselected) and 'Manual' (selected). Under 'Manual', there is a text input field for 'Rock Z-Offset (m)' containing the value '5.00', followed by a label '(Multi Start Value = 5.00)'. Below this is a checked checkbox for 'Use Multi'. To the right of the checkbox are two more input fields: 'Delta (m)' containing '5.00' and 'Steps' containing '10'.

Figure 6-12: Input mask for the ROCK Z-Offset with Multi (Delta and Steps)

For example (see Figure 6-12 and Figure 6-13):

- Initial offset = 5 m
- Delta = 5 m
- Steps = 10

This configuration generates release heights of 5 m, 10 m, 15 m, ... up to 50 m.

Using the Multi option increases the total number of simulations proportionally and should therefore be applied with consideration of computational cost.

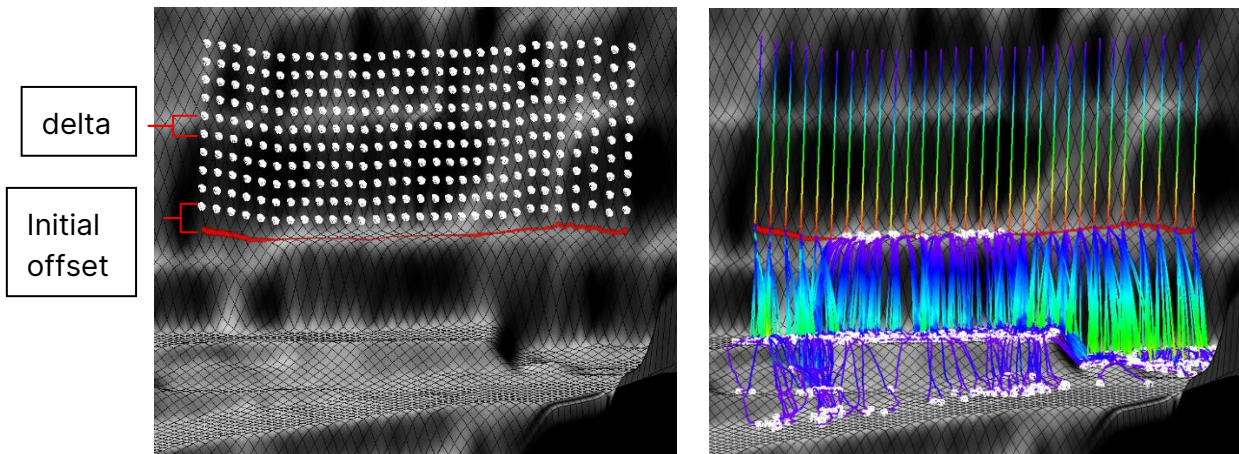


Figure 6-13: Manual definition of rock Z-offset using the Multi option. Multiple release heights are generated by applying a vertical increment (Delta) over a specified number of steps, allowing simulation of rock release from extended cliff sections.

Care must be taken to ensure that the selected offset is sufficiently large to prevent the rock from intersecting the terrain at initialization.

6.1.7 Stop Tab

The **Stop** tab (Figure 6-14) defines the conditions under which individual rock trajectories and the simulation itself are terminated. RAMMS evaluates these criteria continuously during the simulation, and a rock is stopped when the defined threshold conditions are met.

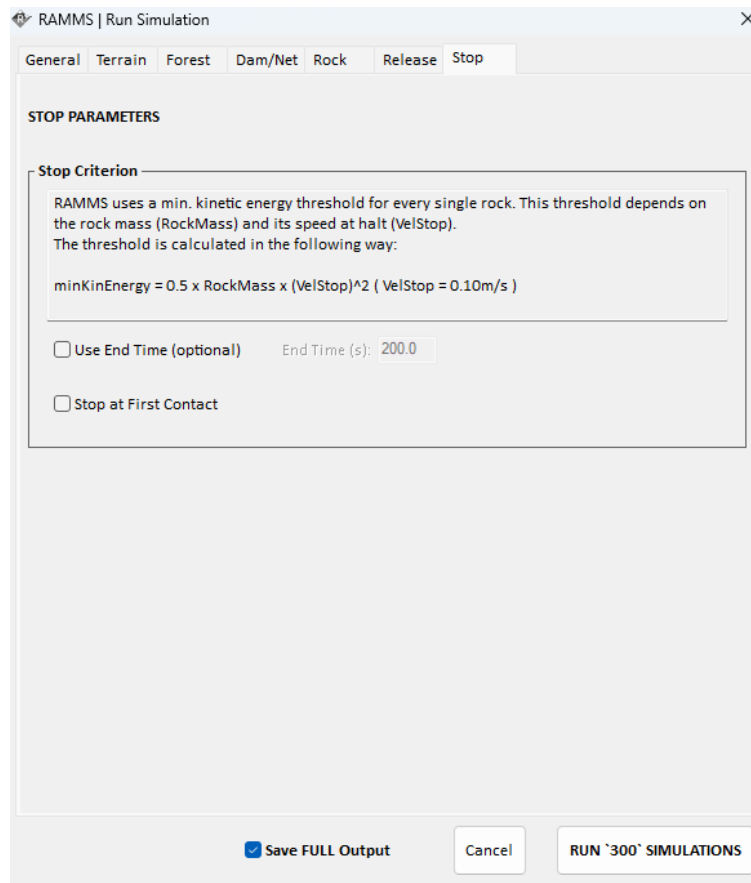


Figure 6-14: Run Simulation window – Stop tab.

Stop Criterion

By default, RAMMS applies an energy-based stopping criterion to each simulated rock. The simulation assigns a minimum kinetic energy threshold below which a rock is considered to have come to rest. This threshold depends on the rock mass and a predefined stopping velocity:

$$\text{minKinEnergy} = \frac{1}{2} \cdot \text{RockMass} \cdot (\text{VelStop})^2$$

where:

- **RockMass** is defined in the Rock tab, and
- **VelStop** is the stopping velocity (default: 0.10 m/s).

Once the kinetic energy of a rock falls below this threshold, its motion is terminated. This approach ensures that stopping behavior is physically consistent and scaled to the size of the simulated blocks.

The stopping velocity (**ROCK_STOP_VEL**) can be modified in the advanced program settings via: **Help** → **Advanced...** → **Additional Preferences...** → **Edit**.

End Time (optional)

The option **Use End Time (optional)** allows the user to define a maximum simulation duration (in seconds). When activated, the simulation will stop once this time limit is reached, regardless of whether all rocks have met the energy-based stopping criterion.

This option is typically used to:

- limit computational time in large simulations, or
- enforce a consistent simulation duration across multiple runs.

If not activated, the simulation continues until all rocks satisfy the stopping criterion.

Stop at First Contact

The **Stop at First Contact** option terminates the motion of a rock immediately upon its first interaction with the terrain surface. This option effectively suppresses bouncing and rolling processes after the initial impact.

This setting is primarily intended for specialized analyses, such as:

- identifying first-impact locations, or
- simplifying simulations where post-impact motion is not relevant.

Combined Stopping Behavior

RAMMS evaluates all active stopping conditions simultaneously. The simulation stops each rock (or the entire run) when the first applicable criterion is reached. In practice, this means that:

- rocks typically stop due to the kinetic energy threshold,
- but may also stop earlier if an end time is reached or if the first-contact condition is enabled.

Careful selection of stopping parameters is important to ensure realistic runout distances and physically meaningful results.

6.2 Selecting Representative Simulation Scenarios

In practical applications, RAMMS::Rockfall should usually be applied using a **set of representative scenarios** rather than a single simulation. Rockfall behavior depends strongly on block size, rock shape, release geometry, terrain properties, forest conditions, and initial conditions. For this reason, the user should define a limited number of physically plausible and well-documented scenarios that together represent the expected range of rockfall behavior at the site.

A simulation scenario in RAMMS is defined by the combined choices made in the **General, Terrain, Forest, Dam/Net, Rock, Release, and Stop tabs**. Changing any of these inputs may alter the resulting trajectories, runout distances, jump heights, impact energies, and reach probabilities. The aim of scenario selection is therefore not to identify a single “correct” model run, but to explore a defensible range of possible rockfall behavior based on field evidence and engineering judgement.

6.2.1 Why Multiple Scenarios Are Needed

Rockfall processes are highly variable. Even with an identical release zone, different rock shapes, sizes, orientations, and terrain interactions can produce substantially different outcomes. This variability is not a numerical artifact, but a fundamental characteristic of rockfall motion.

Several factors commonly require more than one simulation scenario:

- uncertainty in the size of potentially detachable blocks
- uncertainty in the shape of the falling rocks
- uncertainty in the exact release location within a source area
- spatial variability in terrain and forest properties
- uncertainty in the most appropriate mechanical ground parameters
- variability introduced by random initial rock orientations

For this reason, representative rockfall modelling should generally include multiple simulations that bracket the most relevant combinations of input assumptions. Depending on the purpose of the study, this may involve:

- comparing small, medium, and large block volumes
- testing different realistic rock shapes
- comparing point, line, and area releases
- evaluating alternative terrain classifications
- testing the effect of forest inclusion or omission

The selected scenarios should reflect the geological and geomorphological understanding of the site and should be documented transparently. Typical scenario dimensions and their influence are summarized in

Table 6.1.

Table 6.1: Typical scenario dimensions in RAMMS::Rockfall and their influence on simulation results.

Scenario dimension	Typical options	Main effect on results	Recommended approach
Block volume	Small/medium/large	Runout distance, impact energy, jump height	Use at least 2–3 representative volume classes
Rock shape	Equant/flat/elongated/ multiple real rocks	Rotation, rebound, lateral spread	Prefer realistic *.pts rocks; test more than one shape where relevant
Release geometry	Point/ line/area	Start-point distribution, lateral spread, endpoint spread	Match to geological source uncertainty
Terrain properties	Default terrain category/shapefile-based classes	Energy dissipation, rebound, runout	Base on field mapping and test plausible alternatives
Forest conditions	No forest/mapped forest/ alternative densities	Velocity reduction, stopping, deviation	Include forest only where reliably defined
Initial conditions	Automatic or manual Z-offset, optional initial velocity	First impact energy, initial motion	Use default settings unless specific release mechanics justify changes

6.2.2 Selecting Representative Block Volume Classes

The selection of representative block volumes is a geological and geomorphological task that precedes simulation. The user must decide which block sizes are relevant for the investigated slope and the engineering question being addressed.

Representative block volumes should be based, where possible, on:

- field measurements of detached and deposited blocks
- observations of potentially detachable rock masses in the source area
- historical event documentation
- engineering design requirements
- expert judgement based on local lithology, jointing, and slope structure

In many applications, it is useful to distinguish at least three block-size scenarios:

- **Small / frequent events** – blocks that detach relatively often and usually have shorter runout and lower impact energies

- **Medium / representative events** – blocks corresponding to a typical design scenario
- **Large / rare events** – blocks representing the largest documented or geologically plausible releases

The purpose of these classes is not to imply exact recurrence intervals, but to ensure that the range of relevant block sizes is covered in the modelling.

When using realistic rocks created in the Rock Builder, the user should ensure that the selected rock volumes and dimensions are consistent with field evidence. If several volume classes are modelled, each should be saved and named clearly so that the corresponding scenario can be traced unambiguously in the output.

Table 6.2: Example classification of representative block volume scenarios.

Scenario class	Typical interpretation	Main purpose in modelling
Small	Frequent, lower-magnitude detachment	Identify common trajectories and frequent impact areas
Medium	Representative engineering design block	Assess expected design velocities, energies, and jump heights
Large	Rare, high-magnitude or worst credible block	Assess conservative runout and high-energy impact zones

6.2.3 Selecting Representative Rock Shapes

Rock shape has a major influence on rockfall behavior and should be selected with the same care as block volume. As explained in the Rock tab section, realistic rock geometries are preferred because they produce more realistic impact torques, rotations, and rebound behavior than spheres or cuboids.

Where possible, representative rock shapes should be derived from:

- field observations of detached or deposited blocks
- photographs or scans of characteristic blocks
- mapped lithological structure and fracture patterns
- typical shape classes observed in the source area

In practice, the user may select one or more of the following approaches:

- a single representative realistic rock shape
- several realistic rocks stored in a folder
- a small set of contrasting shapes, such as equant, flat, and elongated

Using multiple representative rock shapes is particularly useful when the source area contains blocks with markedly different geometries or when the sensitivity of the results is expected to be high.

If several rocks are included in a folder, all of them are used in the simulation. This can improve the statistical robustness of the results and better represent natural variability in block geometry.

Table 6.3: Recommended rock-shape strategy for different modelling objectives.

Modelling objective	Recommended rock-shape approach
Quick preliminary test	One representative realistic rock
Standard engineering study	One to three representative realistic rocks
Sensitivity analysis	Contrasting shapes (equant, flat, elongated)
Ensemble modelling	Folder containing several realistic *.pts rocks

6.2.4 Selecting Release Configurations

The release configuration defines where the rocks start and how this spatial uncertainty is represented in the simulation. Release zones are typically derived from geological interpretation, orthophotos, terrain analysis, field mapping, or historical observations.

Three principal release geometries are available:

- **Point release** – suitable where the detachment location is known precisely
- **Line release** – suitable where detachment may occur along a cliff edge or narrow source band
- **Area release** – suitable where the exact detachment location is uncertain within a broader source zone

The selected release geometry strongly affects the lateral spread and spatial distribution of the simulated trajectories. Point releases tend to produce concentrated results, whereas area releases generally produce a wider spread of trajectories and impact locations.

In addition to release geometry, the user should also consider:

- the number of release points
- the number of random orientations
- whether manual Z-offset is needed for cliff release
- whether multiple release heights are appropriate

Where source uncertainty is high, area releases are usually more representative than single points. Where the source is well constrained, a point or line release may be more appropriate.

Table 6.4: Release geometry types and recommended use.

Release geometry	Recommended use	Main influence on results
Point	Single known detachment point	Concentrated trajectory cluster
Line	Cliff edge or narrow detachment band	Elongated start distribution, moderate spread
Area	Spatially uncertain or diffuse source zone	Broader lateral spread and endpoint distribution

6.2.5 Combining and Documenting Scenarios

In most practical studies, several scenarios are required to capture the relevant range of rockfall behavior. These scenarios should be defined systematically and named consistently.

A useful naming convention should indicate at least:

- block volume or size class
- rock shape or rock file
- release configuration
- terrain or forest variant, if changed

Examples of descriptive scenario names include:

- Area_1.0m3_Equant
- Line_3.0m3_Long
- Area_1.0m3_RealRock_ForestOn
- Area_1.0m3_RealRock_TalusConservative

Clear naming is particularly important because RAMMS stores outputs by scenario name in the scenario directory. If a scenario with the same name already exists, RAMMS will ask whether the existing scenario should be overwritten. If the user confirms this action, the previous scenario folder and all associated files are deleted and replaced by the new simulation results. It is therefore recommended to use unique and descriptive scenario names throughout a modelling study.

For reproducibility, the user should also decide whether to reuse existing random orientations. In RAMMS, initial rock orientations are generated randomly for each simulation unless a previously saved set of orientations is loaded. This means that two simulations with otherwise identical settings may produce slightly different results.

If an exact reproduction of a previous simulation is required, the user should load the corresponding .random.sav file from the output directory of the earlier scenario. If not, RAMMS generates a new set of random orientations and stores them in the new scenario folder.

Table 6.5: Recommended information to encode in scenario names.

Element	Example	Purpose
Release type	Point / Line / Area	Identifies source representation
Block size	0.3m ³ / 1.0m ³ / 3.0m ³	Identifies volume class
Rock shape	Equant / Flat / Long / RealRock01	Identifies geometry used
Parameter variant	ForestOn / ForestOff / TalusAlt	Identifies sensitivity or assumption set

6.2.6 Recommended Workflow for Scenario Preparation

Before running full production simulations, it is recommended to proceed in two steps. First, perform a **test simulation** using a reduced number of trajectories in order to verify that:

- the DEM is correctly loaded
- the release zone is correctly defined
- terrain categories are assigned as intended
- forest data are included correctly, if used
- the selected rock file and density are appropriate
- the simulation end conditions allow sufficient runout
- the overall trajectory pattern is plausible

A small trial run with a modest number of trajectories can reveal setup errors early and reduce unnecessary computation time.

Second, once the setup has been checked, run the **full ensemble simulation** using the complete set of representative scenarios and a sufficient number of random orientations to obtain stable statistical results.

If terrain and/or forest shapefiles are included, RAMMS prepares the scenario by assembling the relevant input data and writing the required parameter files before the actual simulation starts. Progress messages are shown in the status bar, followed by a simulation progress indicator. After the run is completed, RAMMS creates the scenario logfile and writes the corresponding output files to the scenario directory.

Table 6.6: Suggested two-stage workflow for scenario preparation.

Stage	Purpose	Typical outcome
Test run	Verify setup and detect errors	Plausibility check of trajectories and model setup
Full run	Produce statistically meaningful output	Final trajectories, maps, and scenario outputs

6.2.7 Practical Recommendations

The following practical recommendations are suggested for scenario selection in RAMMS::Rockfall:

- Use more than one scenario whenever block size, shape, or release location is uncertain.
- Base block volume classes and representative rock shapes on field observations whenever possible.
- Prefer realistic rock geometries generated with the Rock Builder over spheres or cuboids.
- Use area releases where the source zone is uncertain and point releases only where detachment is well constrained.
- Carry out an initial test run before launching the full simulation ensemble.
- Use clear and unique scenario names to avoid accidental overwriting of results.
- Reuse saved random orientations only when exact reproducibility of a previous simulation is required.

6.2.8 Scenario Files and Storage Optimization

After a simulation scenario is executed, RAMMS automatically creates a dedicated **scenario folder** within the project directory. This folder contains all files required to store, reproduce, and analyse the simulation results.

The scenario folder includes:

- trajectory data
- raster output maps (e.g. velocity, energy, jump height)
- shapefiles describing trajectories and start positions
- summary and log files documenting the simulation

These files together represent the complete numerical result of the simulation and allow post-processing, visualization, and comparison between scenarios.

Typical output files generated by RAMMS include:

- <scenario_name>_Trajectories.shp – Shapefile containing all simulated trajectories as 2D polylines
- <scenario_name>_StartPositions.shp – Shapefile containing all release points
- <scenario_name>_Nr of Rocks.tif – Raster showing the number of rocks passing each grid cell
- <scenario_name>_Jump Height (m) – Q95%.tif – Raster of the 95th percentile jump height
- <scenario_name>_Velocity (m s⁻¹) – Q95%.tif – Raster of the 95th percentile velocity
- <scenario_name>_Kinetic Rock Energy (kJ) – Q95%.tif – Raster of the 95th percentile kinetic energy
- <scenario_name>_Source Reach Probability (%).tif – Raster showing the proportion of trajectories reaching each cell
- <scenario_name>_endpoints.txt – Text file listing all final deposition coordinates

In addition, RAMMS stores auxiliary files such as:

- simulation log files
- random orientation files (*.random.sav)
- intermediate trajectory data

These files ensure that simulations can be reproduced and results can be traced back to their input assumptions.

Storage Optimization of Trajectory Data

To optimize storage and improve performance when handling large numbers of trajectories, RAMMS applies a data reduction technique to the trajectory shapefiles.

The trajectories stored in <scenario_name>_Trajectories.shp are simplified using the **Ramer–Douglas–Peucker (RDP) algorithm**. This algorithm reduces the number of points in each trajectory while preserving its overall shape.

The method works by removing points that do not significantly change the direction of the trajectory:

- Points close to a straight line are removed
- Points representing significant changes in direction are retained

The level of simplification is controlled by a tolerance parameter (ϵ):

- Small ϵ → high level of detail, larger file size
- Large ϵ → stronger simplification, smaller file size

This approach significantly reduces file size and improves performance during visualization and post-processing, while maintaining an accurate representation of the rockfall trajectories.

6.3 Executing the Simulation and Generated Outputs

Once all parameters in the Run Simulation window have been defined and verified, the simulation can be started by clicking the **RUN "XXX" SIMULATIONS** button. RAMMS then performs a sequence of preparation steps followed by the numerical simulation and automatic generation of output files.

This section describes the execution workflow, user interactions during simulation start, and the structure of the generated outputs.

6.3.1 Scenario Overwrite and Naming

If a scenario with the same name already exists in the output directory of the project, RAMMS prompts the user to confirm whether the existing scenario should be overwritten.

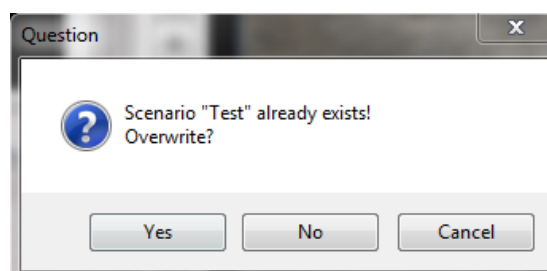


Figure 6-15: Scenario already exists dialogue.

- **Yes** – The existing scenario folder, including all files and subdirectories, is deleted and replaced by the new simulation results
- **No / Cancel** – The simulation is not started, and the user can modify the scenario name in the General tab

Because overwriting permanently deletes previous results, it is strongly recommended to use **unique and descriptive scenario names** for each simulation.

6.3.2 Random Orientations and Reproducibility

Rockfall simulations in RAMMS include a stochastic component: the initial orientation of each rock is randomly assigned unless a predefined set of orientations is provided. As a result, two scenarios with identical input parameters may produce slightly different results.

The user has two options:

- Load existing random orientations from a previous simulation
- Generate a new set of random orientations

If reproducibility is required, the user can check the checkbox “**Use existing random orientations**” in the Release-Tab (see section 6.1.6), and is then asked to load a previously saved orientation file:

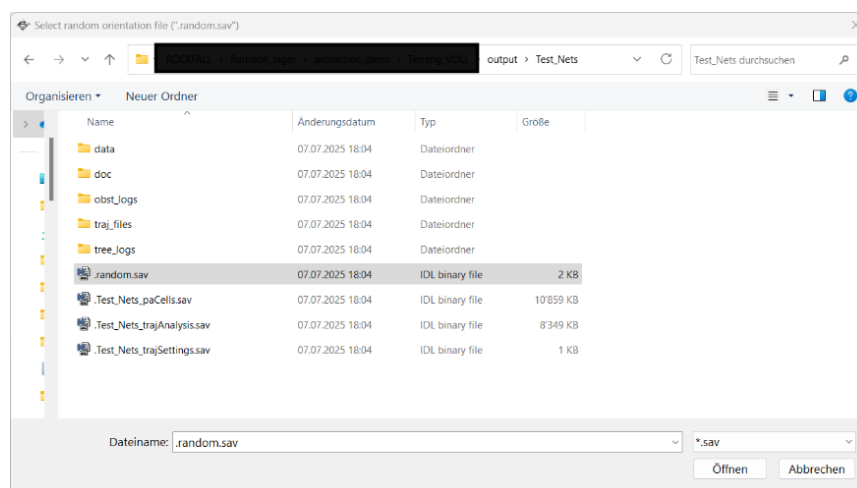


Figure 6-16: Selecting previously generated random orientations.

- Navigate to: ../ProjectName/output/ScenarioName/
- Select the corresponding .random.sav file

If new orientations are generated, RAMMS automatically stores them in the scenario folder for future reuse.

6.3.3 Scenario Preparation

After confirming the initial settings, RAMMS prepares the simulation by assembling all required input data.

If terrain and/or forest shapefiles are defined, RAMMS processes these inputs and generates the corresponding parameter files (e.g. friction and forest interaction parameters). Progress messages are displayed in the status bar.

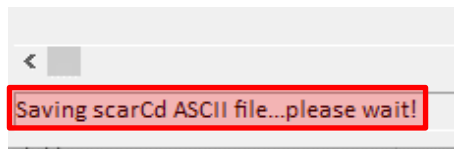


Figure 6-17: Saving friction parameter ASCII files during scenario preparation.

This preparation step ensures that all spatial inputs and parameters are correctly assigned before the numerical simulation begins.

6.3.4 Simulation Execution

Once preparation is complete, RAMMS starts the numerical simulation.

A progress indicator is displayed (Figure 6-18), showing the status of the computation.

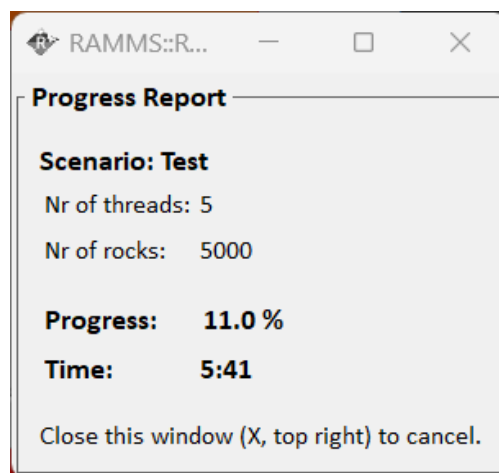


Figure 6-18: Rockfall simulation progress window.

During the simulation:

- each trajectory is computed independently
- calculations are distributed across the selected number of threads
- results are written to memory and output files according to the dump step

The total simulation time depends on:

- number of trajectories
- complexity of terrain and forest data
- number of rock shapes
- number of CPU threads used

The simulation can be interrupted at any time by clicking **the top right X**.

6.3.5 Scenario Logfile

After the simulation is completed (or interrupted), RAMMS displays the **Scenario Logfile** (Figure 6-19).

The logfile provides a record of the simulation, including:

- input parameters and settings
- number of simulated trajectories
- processing steps and messages
- potential warnings or errors

The logfile is stored in the scenario directory and serves as documentation of the simulation setup and execution.

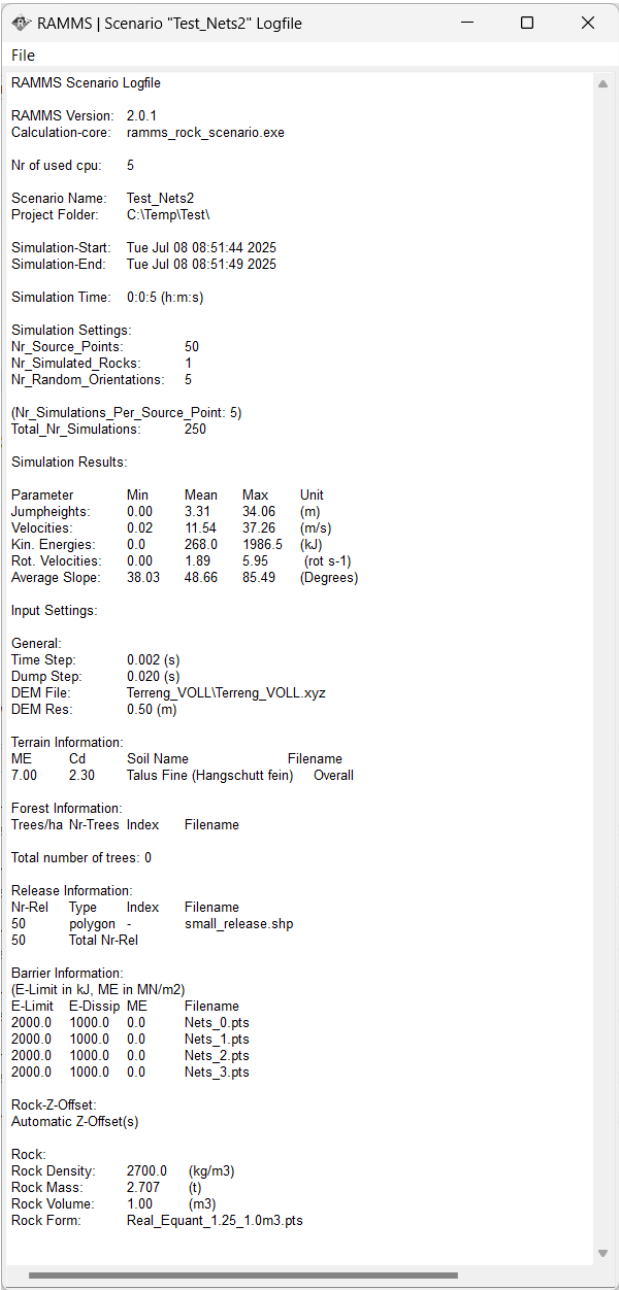


Figure 6-19: RAMMS Scenario Logfile

6.3.6 Generated Output Files

After completion, RAMMS automatically creates a set of output files in the scenario folder. These files contain the simulated trajectories and derived statistical results.

The most important outputs include:

Vector Data

- <scenario_name>_Trajectories.shp
Shapefile containing all simulated trajectories as 2D polylines (x/y coordinates)
Attributes include:
 - trajectory file reference
 - rock name
 - <scenario_name>_StartPositions.shp
Shapefile containing all release point locations

Raster Data (GeoTIFF)

- <scenario_name>_Nr of Rocks.tif
Number of rocks passing through each grid cell
- <scenario_name>_Jump Height (m) – Q95%.tif
95th percentile jump height
- <scenario_name>_Velocity (m s⁻¹) – Q95%.tif
95th percentile velocity
- <scenario_name>_Kinetic Rock Energy (kJ) – Q95%.tif
95th percentile kinetic energy
- <scenario_name>_Source Reach Probability (%).tif
Percentage of trajectories reaching each grid cell

Text Output

- <scenario_name>_endpoints.txt
Text file containing the coordinates of all final deposition points

These outputs form the basis for further analysis in RAMMS or in external GIS software.

6.3.7 Recommended Execution Workflow

To ensure reliable and efficient simulations, the following workflow is recommended:

1. **Verify all inputs before running:**

- DEM correctly loaded
- release zones defined
- terrain categories assigned
- forest data assigned (if applicable)
- rock properties defined
- stopping conditions appropriate

2. **Perform a test run:**

- use a reduced number of trajectories (e.g. 50–100)
- verify plausibility of trajectories and outputs

3. **Run the full simulation:**

- increase number of trajectories (e.g. 500 or more)
- ensure sufficient random orientations for statistical stability

4. **Check results and logfile:**

- review trajectory patterns
- verify that outputs are physically plausible
- inspect logfile for warnings or errors

This stepwise approach reduces the risk of configuration errors and improves the reliability of the final results.

6.3.8 Notes on Result Interpretation

The outputs generated by RAMMS represent a **statistical ensemble of simulated trajectories** based on the defined scenario.

Key output quantities such as:

- reach probability
- jump height (Q95)
- velocity (Q95)
- kinetic energy (Q95)

are **conditional on the selected input parameters**, including:

- release configuration
- rock size and shape
- terrain and forest properties
- number of simulations

They do not represent absolute probabilities or return periods unless additional assumptions about event frequency are introduced.

Results should therefore always be interpreted in the context of the selected scenario and, where necessary, compared across multiple scenarios to assess variability and uncertainty.

7 Results

RAMMS::Rockfall provides two complementary result analysis modes:

- **Statistics Mode** – ensemble-based evaluation of many simulated trajectories
- **Trajectory Mode** – detailed inspection of individual trajectories

This chapter describes the full functionality of Statistic Mode, including:

- Statistical evaluation methodology
- Distribution visualization
- Report generation
- Probability analyses
- Impact analyses
- Design-oriented tools (SOL, gallery, obstacles)

Trajectory Mode is described separately.

RAMMS output is evaluated in Statistic Mode (ensemble view of all trajectories) and Trajectory Mode (individual rock paths). Key output maps are maximum kinetic energy, jump height, velocity, and rock count per cell. Use the built-in statistical tools to derive design values (e.g. 95th percentile energy) for hazard mapping and protection measure dimensioning.

7.1 Statistics Mode

Statistic Mode is used to analyze large sets of simulated trajectories (> 100). It answers questions such as:

- Which cells are affected?
- How many rocks pass through a cell?
- What are representative values (mean, Q95, Q99, max)?
- What is the probability that rocks reach a location?

All statistical evaluations are performed per raster cell.

Statistics Mode evaluates all trajectories per raster cell and provides representative values such as:

- **Mean**
- **Median**
- **Q90 / Q95 / Q99**
- **Maximum**
- **Reach probability**
- **Number of rocks**

Each raster cell contains all trajectory values that passed through it.

7.1.1 Cell-Based Data Storage

For every raster cell intersected by trajectories, RAMMS stores:

- **Jump height (H)**
- **Translational velocity (V)**
- **Rotational velocity**
- **Kinetic energy (E)**
- **Scar length**
- **Scar depth**

All values are treated as numeric samples of the parameter distribution. Invalid values (e.g., NaN/Inf) are excluded from statistical evaluation and plotting.

All 34 Data Values (+ Output File Name):				
JumpH	Vel	KinE	RotV	Filename
3.25	18.90	589.44	3.07	Example_Pos14_PTSReal_Flat_1.77_1.0m3_O17.rts
1.86	11.43	197.95	1.42	Example_Pos14_PTSReal_Flat_1.77_1.0m3_O4.rts
0.76	4.19	31.25	0.92	Example_Pos15_PTSReal_Flat_1.77_1.0m3_O2.rts
3.13	11.61	219.55	1.77	Example_Pos19_PTSReal_Flat_1.77_1.0m3_O6.rts
3.20	13.36	300.68	2.65	Example_Pos19_PTSReal_Flat_1.77_1.0m3_O8.rts
2.12	9.09	143.55	1.82	Example_Pos22_PTSReal_Flat_1.77_1.0m3_O18.rts
1.16	24.07	882.32	3.03	Example_Pos25_PTSReal_Flat_1.77_1.0m3_O1.rts
0.54	25.54	1033.67	3.64	Example_Pos25_PTSReal_Flat_1.77_1.0m3_O20.rts
2.14	10.52	172.44	1.51	Example_Pos25_PTSReal_Flat_1.77_1.0m3_O23.rts
0.84	12.83	270.41	2.18	Example_Pos26_PTSReal_Flat_1.77_1.0m3_O8.rts
0.89	3.72	23.82	0.80	Example_Pos28_PTSReal_Flat_1.77_1.0m3_O25.rts
1.60	18.66	556.01	2.97	Example_Pos35_PTSReal_Flat_1.77_1.0m3_O10.rts
2.05	25.93	1107.84	4.15	Example_Pos35_PTSReal_Flat_1.77_1.0m3_O3.rts
0.60	4.60	33.90	0.86	Example_Pos37_PTSReal_Flat_1.77_1.0m3_O11.rts
2.24	32.13	1594.28	4.21	Example_Pos37_PTSReal_Flat_1.77_1.0m3_O17.rts

Figure 7-1: Example of trajectory values stored in one cell

7.1.2 Descriptive Statistics

From each cell-based sample set, RAMMS computes:

Central tendency

- Mean
- Median (50% quantile)

Spread

- Standard deviation
- Interquartile range (IQR)

Extreme values

- Maximum (The maximum value represents one trajectory only and is not statistically robust).

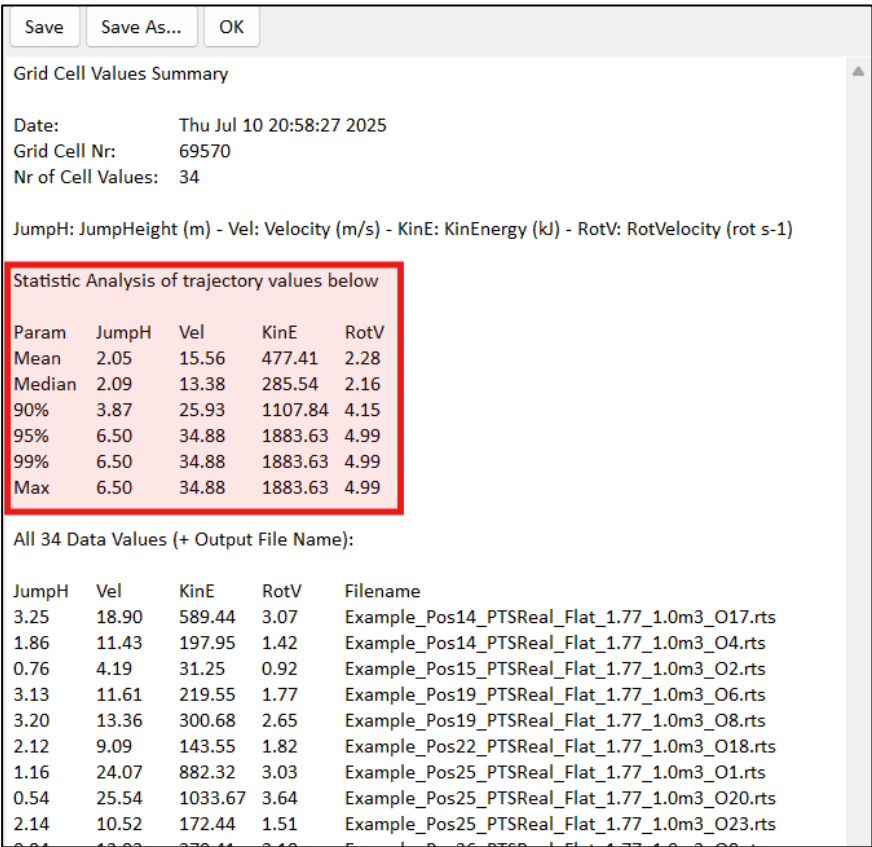


Figure 7-2: Statistic summary

7.1.3 Quantile Calculation Method

Quantiles (Q1, Q3, Q90, Q95, Q99, etc.) are computed as follows:

- Sort sample values in ascending order
- Compute rank: $r = p \cdot (n - 1)$
- Linearly interpolate between neighbouring indices

This method:

- Is numerically stable
- Avoids special even/odd handling
- Ensures reproducibility for any sample size

Default quantiles in RAMMS::Rockfall:

- **Q90**
- **Q95**
- **Q99**

These default quantiles can be modified (see Section 7.2.3).

7.1.4 Histogram and Probability Density Function (PDF)

The histogram visualizes the frequency distribution.

Default binning rule:

- Freedman–Diaconis (IQR-based, robust to skewness)
- Fallback to standard deviation rule if necessary

The plotted PDF is normalized:

$$PDF = \frac{\text{counts}}{n \cdot \text{bin width}}$$

The area under the curve equals 1.

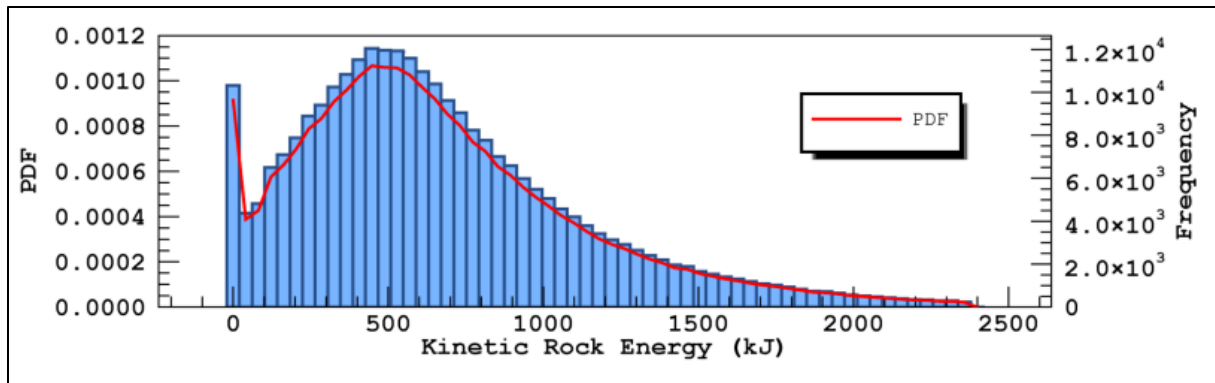


Figure 7-3: Histogram and Probability Density Function (PDF)

Probability Density Function (PDF):

Wikipedia: “The probability density function (PDF), or density of a continuous random variable, is a function that describes the relative likelihood for this random variable to take on a given value. The probability of the random variable falling within a particular range of values is given by the integral of this variable’s density over that range—that is, it is given by the area under the density function but above the horizontal axis and between the lowest and greatest values of the range. The probability density function is non-negative everywhere, and its integral over the entire space is equal to one.”

7.1.5 CDF and EDF

Two cumulative curves may be shown:

Empirical Distribution Function (EDF)

$$EDF(i) = \frac{i + 1}{n}$$

Exact cumulative distribution derived from sorted sample.

Reference Normal CDF

Normal distribution using sample mean and standard deviation. Used only for qualitative comparison.

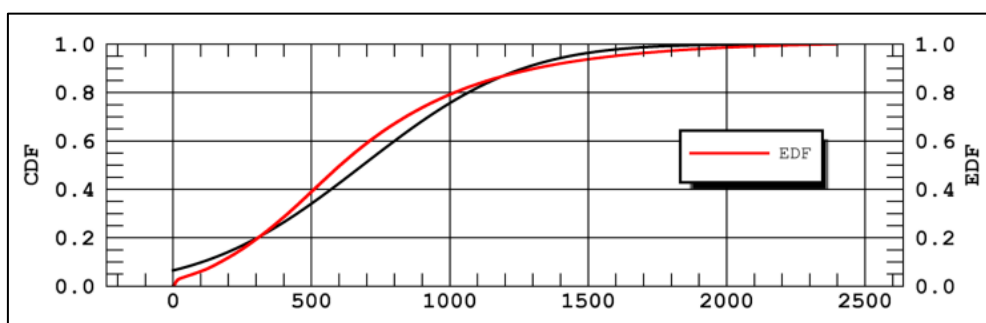


Figure 7-4: Reference Normal CDF and Empirical Distribution Function (EDF)

Cumulative Distribution Function (CDF):

Wikipedia: "In probability theory and statistics, the cumulative distribution function (CDF), or just distribution function, describes the probability that a real-valued random variable X with a given probability distribution will be found to have a value less than or equal to x ."

Empirical Distribution Function (EDF):

Wikipedia: "In statistics, the empirical distribution function is the distribution function associated with the empirical measure of the sample. This cumulative distribution function is a step function that jumps up by $1/n$ at each of the n data points. The empirical distribution function estimates the cumulative distribution function underlying of the points in the sample and converges with probability 1 according to the Glivenko–Cantelli theorem."

7.1.6 Boxplot Representation

The boxplot summarizes:

- **Q1 (25%)**
- **Median**
- **Q3 (75%)**
- **IQR**
- **Min / Max**
- **Outliers**

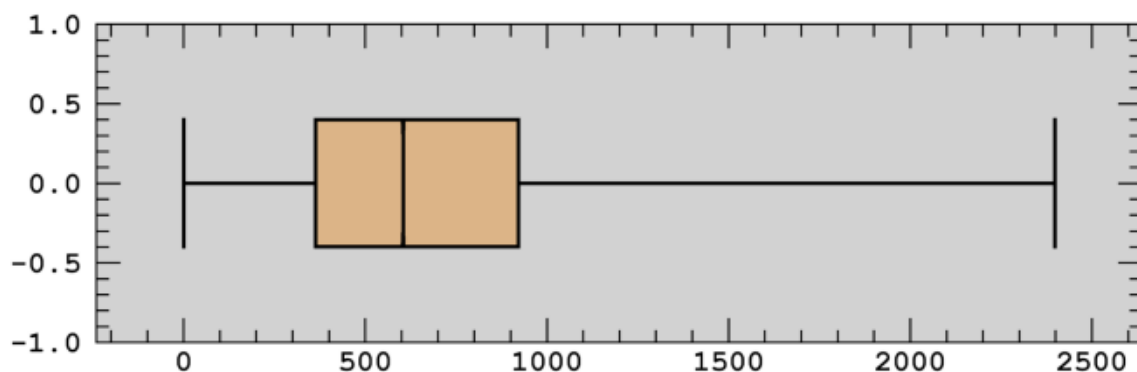


Figure 7-5: Boxplot Representation

Useful to quickly identify skewed or heavy-tailed distributions.

Boxplot:

Wikipedia: “In descriptive statistics, a box plot or boxplot is a convenient way of graphically depicting groups of numerical data through their quartiles. Box plots are non-parametric: they display variation in samples of a statistical population without making any assumptions of the underlying statistical distribution. The spacings between the different parts of the box indicate the degree of dispersion (spread) and skewness in the data, and show outliers.”

7.1.7 Implementation Refinements (since Version 2.0)

Compared to earlier versions:

- Percentile definition standardized
- PDF scaled as true density
- Robust binning rule implemented
- EDF computed directly from sample

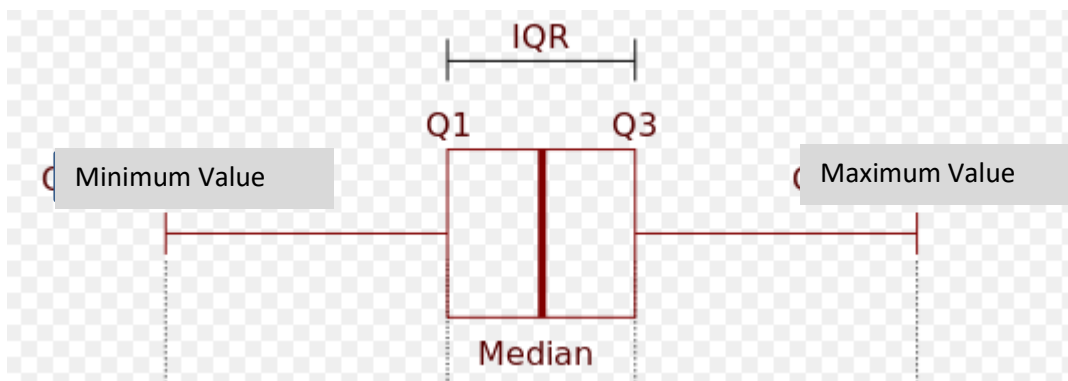


Figure 7-6: Boxplot Explanations (Q1: lower quartile = 25 %, Q3: upper quartile = 75 %, IQR: interquartile range).

Users may observe small numerical differences in high percentiles (Q95/Q99). The underlying trajectory results remain unchanged.

Statistic Mode aggregates all simulated trajectories into spatial statistics per grid cell: maximum, mean, median, 90th and 95th percentile values for energy, velocity, and height. Use the 95th percentile energy map as the conservative design basis for protection structures; use the median for most-likely scenario visualisations.

7.2 Working in Statistic Mode

This section describes the complete workflow for opening, filtering, combining, and evaluating rockfall simulation results in Statistic Mode.

Statistic Mode is activated automatically when a rockfall scenario is calculated and then opened, or opened later by the user.

7.2.1 Opening a Rockfall Scenario

To open a simulation result:

Track → Open → Rockfall Scenario

Alternatively, use the toolbar button  for opening a scenario.

You must select the **output folder** of a completed rockfall simulation. This folder contains the trajectory result files.

After selecting the folder and clicking **OK**, RAMMS loads:

- All trajectory files within the folder
- Corresponding statistical information
- Raster result grids

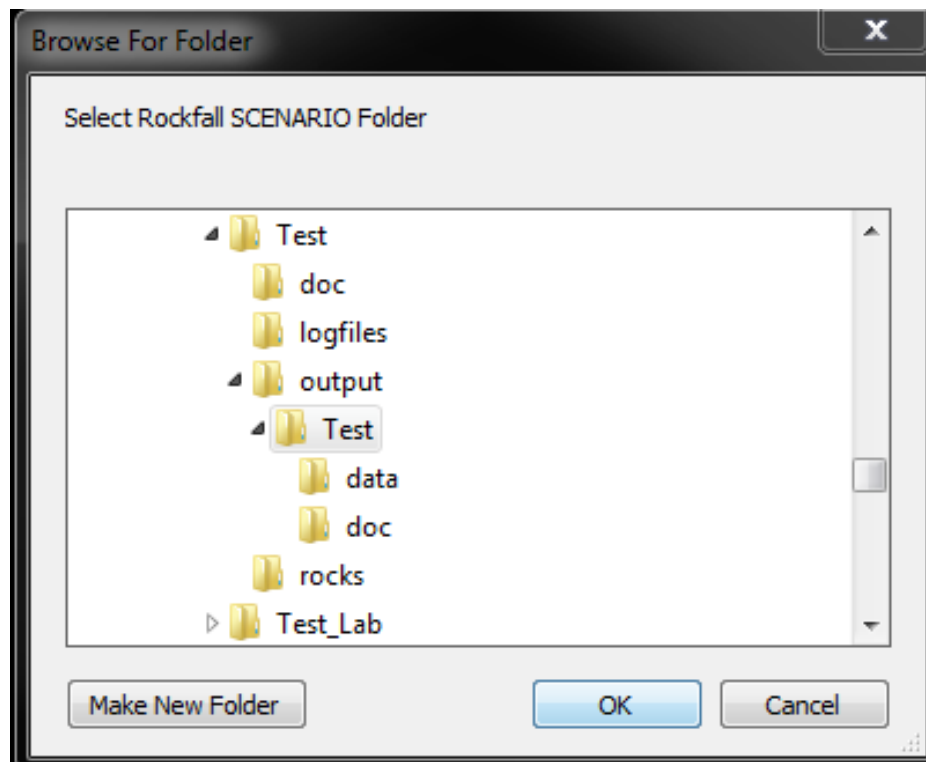


Figure 7-7: Browse for Scenario Folder.

7.2.2 Opening Multiple Scenarios (Filter/Multi)

In many engineering projects, simulations are performed:

- For different block sizes
- For different release areas
- For parameter sensitivity studies
- For mitigation scenarios

To combine several result sets:

Track → Open → Rockfall Scenario (Filter/Multi)

This option allows:

- Filtering files by name
- Selecting subsets of simulations
- Combining multiple scenarios

File Name Filter

In the file filter dialog, you may:

- Enter a file string to restrict which files are opened
- Use multiple filter strings separated by a colon (:)

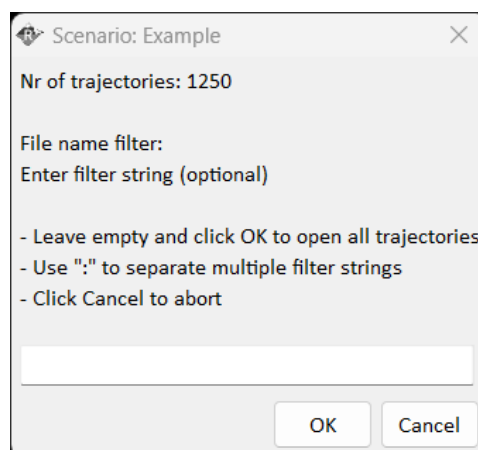


Figure 7-8: The file name filter shows information about the scenario that you are opening. You can enter a file string or click OK to open all files.

Example:

blockA:blockB

This will open all files containing either “blockA” or “blockB”.

If the filter field is left empty, all result files in the folder are opened.

Opening Additional Scenarios

After selecting one scenario, RAMMS asks:

Open more scenarios?

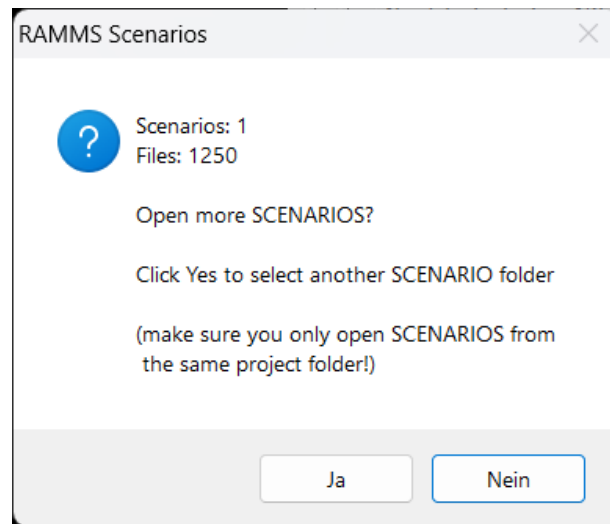


Figure 7-9: Open more Scenarios?

Click:

- **Yes** → select another scenario folder
- **No** → proceed with analysis

Important:

All scenarios must be located in the **same project folder structure**. RAMMS merges trajectory sets internally and performs statistical evaluation on the combined dataset.

7.2.3 Default Result After Opening

After loading a scenario, RAMMS displays:

- The **95% quantile of kinetic rock energy** (kJ)
- Over the full raster domain

The Q95 value is selected by default because it is commonly used as a design value.

The currently selected quantile appears in the dropdown menu in the upper-right toolbar.

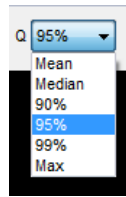


Figure 7-10: Quantile dropdown menu in upper right toolbar.

Changing Default Quantile Selection

The default dropdown position can be modified in:

Help → Advanced → Additional Preferences

Keyword:

QUANTILE

Values between 0–5 correspond to the dropdown position.

Click **Save** and **OK** to save any changes you made.

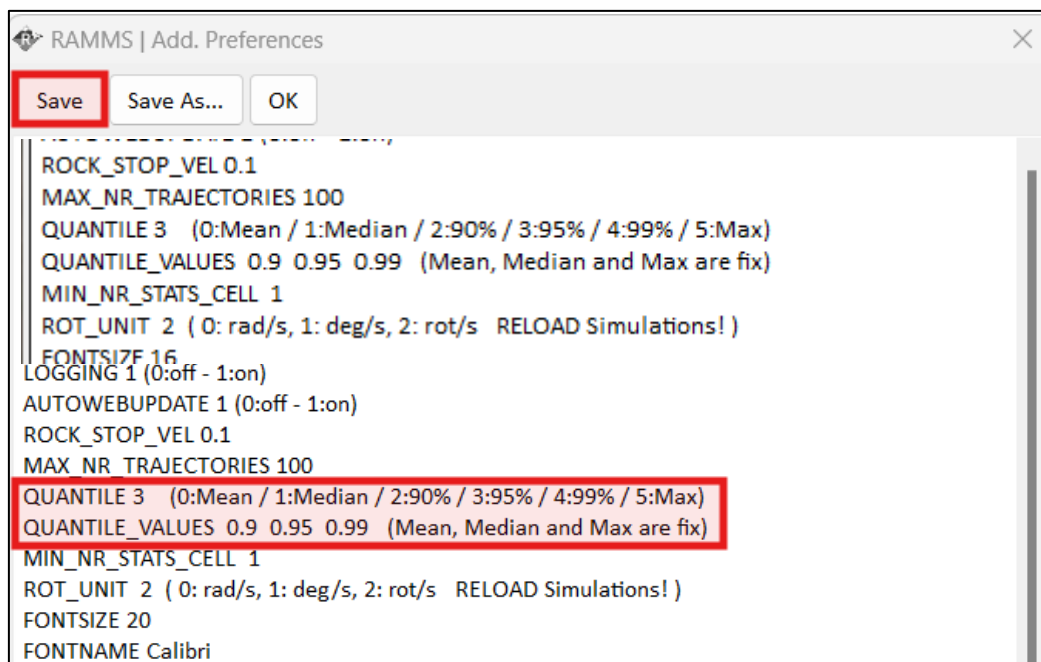


Figure 7-11: Additional Preferences: Quantile Values

7.2.4 Scenario Information Panel (Right Panel)

The right-hand panel contains the **Scenario Tab**, which provides important metadata.

Displayed information includes:

General Information

- Number of trajectories
- Average slope between release and deposition
 - Minimum
 - Mean
 - Maximum

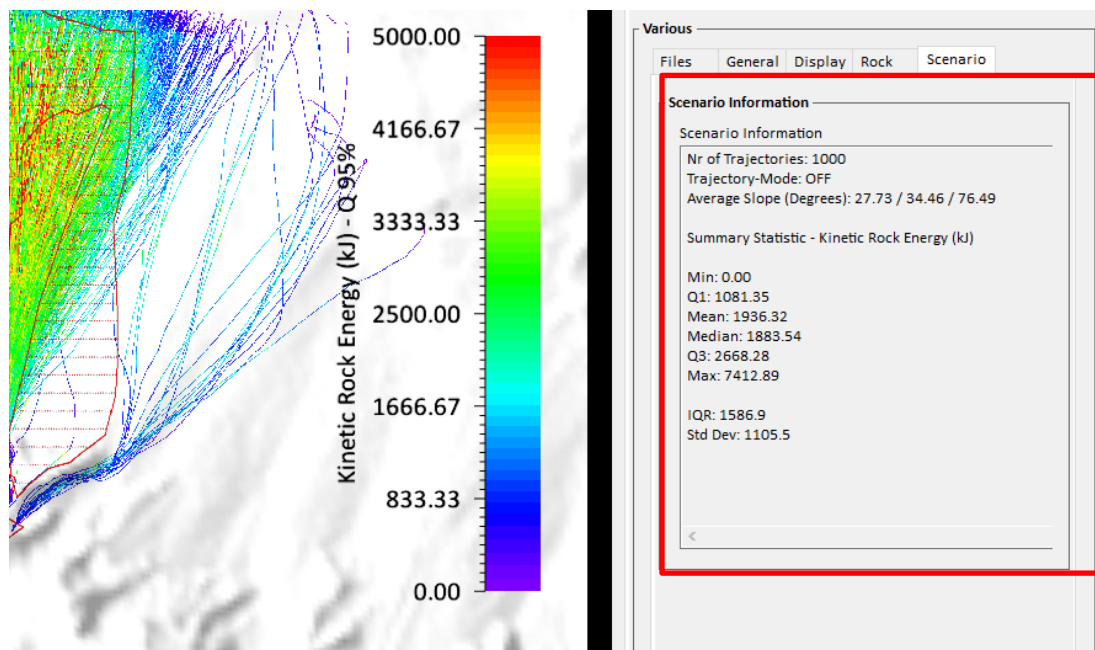


Figure 7-12: Statistic Mode information is shown in the right panel in the Scenario tab. (Min, Q1, Mean, Median, Q3, Max, IQR, StdDev).

- The average slope represents the inclination of a straight line connecting:
 - Start point
 - Deposition point

This provides a quick global characterization of runout behavior.

8-Point Statistical Summary

For the currently selected parameter and statistic:

- Minimum
- Q1 (25%)
- Mean
- Median
- Q3 (75%)
- Maximum
- IQR
- Standard deviation

This summary updates dynamically when:

- Parameter changes
- Quantile selection changes

7.2.5 Available Result Parameters

Statistic Mode provides spatial maps for:

- Jump Height 
- Rock Velocity 
- Resultant Rotational Rock Velocity
- Kinetic Rock Energy 
- Scar Length
- Scar Depth

These parameters can be selected via the results dropdown menu.

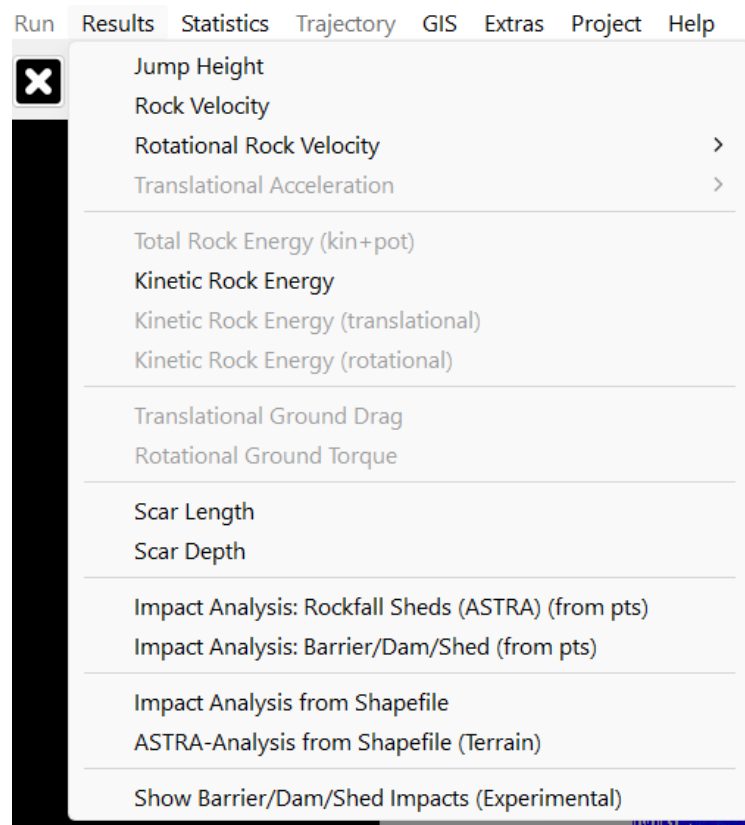
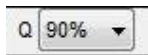


Figure 7-13: Statistics Mode: Dropdown menu Results

All other results are available in *Trajectory Mode* only.

7.2.6 Selecting Statistical Measure

In the upper-right toolbar, a dropdown menu  allows selection of:

- **Mean**
- **Median**
- **Q90**
- **Q95**
- **Q99**
- **Maximum**

The selected measure is applied spatially to all raster cells.

Engineering Recommendation

- Use Q95 for typical structural design.
- Use Q99 for critical infrastructure.
- Avoid using Maximum without reviewing distribution.

7.2.7 Statistics Menu (Top Menu Bar)

The menu **Statistics** provides access to additional evaluation tools.

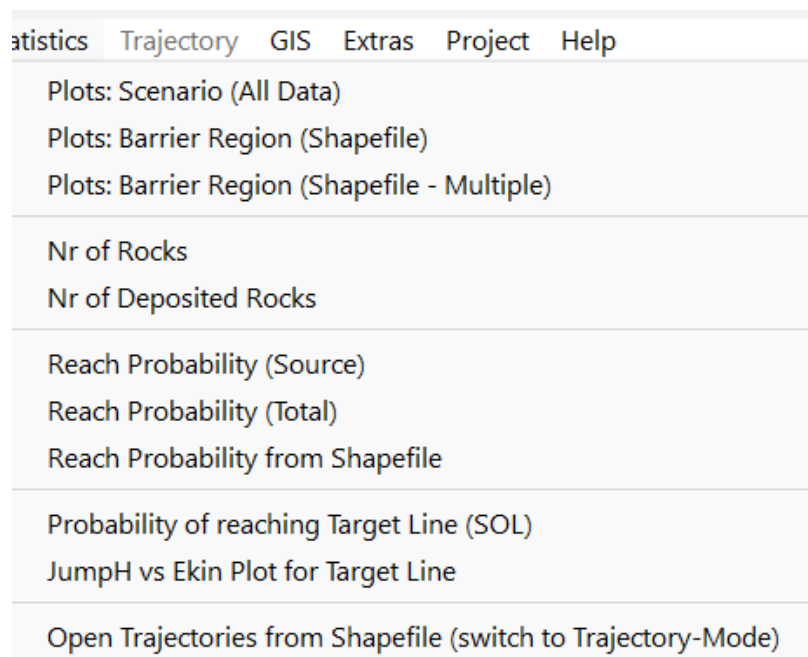


Figure 7-14: Additional evaluation tools in Statistics Mode.

Available options include:

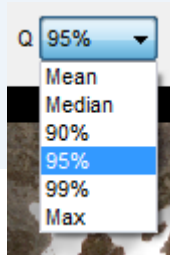
- Plots: Scenario (All Data)
- Plots: Barrier Region (Shapefile)
- Plots: Barrier Region (Shapefile – Multiple)
- Nr of Rocks
- Nr of Deposited Rocks
- Reach Probability (Source)
- Reach Probability (Total)
- Reach Probability from Shapefile

Each of these functions as well as the *Target Line* functions and *Open Trajectories from Shapefile* are described in later sections.

7.2.8 Horizontal Toolbar Functions

The horizontal toolbar provides quick access to:

- Barrier plot 
- Line profile 
- Cell info file 
- Quantile dropdown menu



These tools are frequently used during engineering evaluation.

Line Profile Tool

Used to draw a profile directly in the map window.

Automatically generates:

- Line profile plot
- Barrier Region Report

Cell Info File

Exports statistical values for selected cells into a text file. Useful for external reporting and documentation.

Filter trajectories by release zone, rock size, or energy threshold before generating statistics to isolate specific scenarios. Combining results from multiple scenarios (e.g. different block sizes) gives an integrated hazard picture. Export maps as GeoTIFF for further analysis in GIS.

7.3 Statistical Evaluation and Reporting Tools

The Statistics menu provides advanced evaluation tools that go beyond simple spatial visualization of mean or quantile maps.

These tools allow:

- Generation of engineering reports
- Evaluation of specific protection structures
- Probability assessment
- Quantification of rock frequency

Each function is described in detail below.

7.3.1 Plots: Scenario (All Data)

Menu: **Statistics → Plots: Scenario (All Data)**

This function generates a comprehensive HTML report for the entire scenario domain.

It aggregates all trajectory values for each parameter across all raster cells and produces a statistical summary.

What Is Evaluated?

For each parameter (Jump Height, Velocity, Kinetic Energy, Rotational Velocity, Scar Depth):

- All recorded trajectory values are collected
- Descriptive statistics are computed
- Distribution plots are generated

The evaluation is not limited to a single cell or region — it considers the full spatial domain.

Contents of the HTML Report

The Scenario Report typically includes:

1. Statistical summary table

- **Minimum**
- **Q1**
- **Mean**
- **Median**
- **Q3**
- **Q90 / Q95 / Q99**
- **Maximum**
- **Standard deviation**

2. Histogram and Probability Density Function (PDF)
3. Cumulative Distribution Function (CDF)
4. Empirical Distribution Function (EDF)
5. Boxplot representation

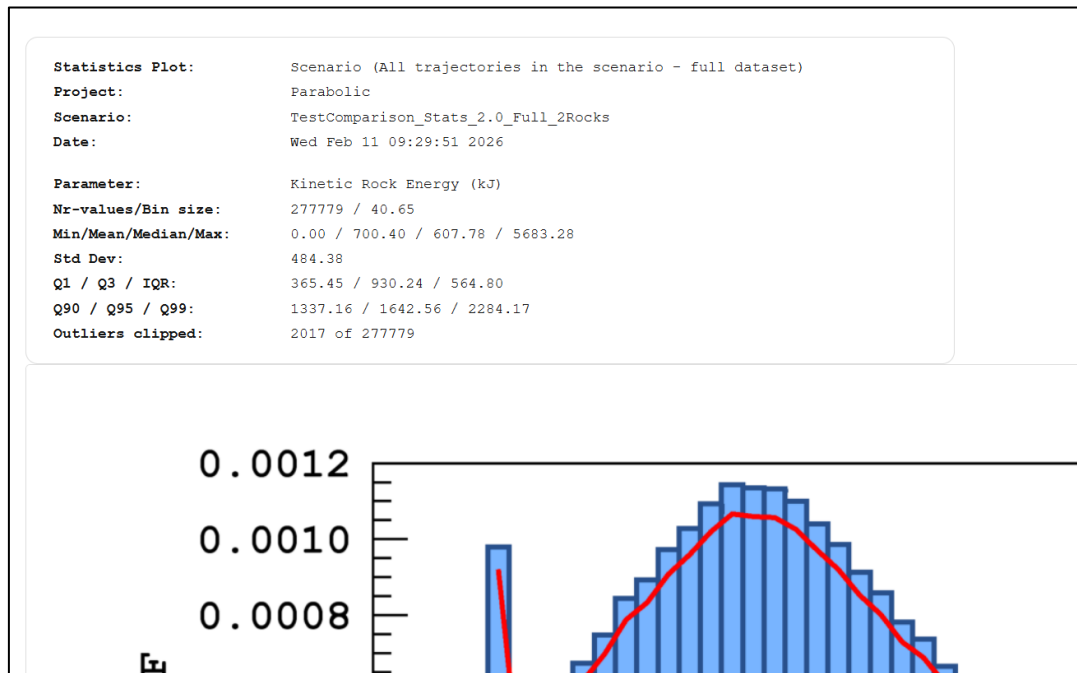


Figure 7-15: Scenario Plot

Engineering Use

The Scenario Report is particularly useful for:

- Global hazard characterization
- Comparing scenarios
- Verifying simulation plausibility
- Understanding distribution shape (skewness, heavy tails)

It is not intended for local design of specific structures - for that, Barrier Region analysis is recommended

Interpretation Guidance

If the histogram shows:

- A long right tail → extreme impacts exist
- Strong skewness → mean may not represent typical behaviour

- Wide IQR → high variability in impact energy

Always examine distribution shape before selecting design quantile.

7.3.2 Plots: Barrier Region (Shapefile)

Menu: **Statistics → Plots: Barrier Region (Shapefile)**



This function generates an HTML report for a specific user-defined region.

The region may be:

- A **polyline shapefile** (e.g. dam crest, road alignment, protection line)
- A **polygon shapefile** (e.g. net field, building footprint, protection area)

This tool is primarily used for **structure-specific engineering design**.

What Is Evaluated?

All trajectory values intersecting the defined region are extracted.

For these values:

- Descriptive statistics are computed
- Distribution plots are generated
- Number of trajectories passing the region
- Number of trajectories stopping within the region

The output is provided as a HTML report.

Special Case: Barrier Plot from a Line Shapefile (Line Profile)



If the Barrier Plot is generated from a **polyline shapefile**, RAMMS automatically creates two outputs:

- The Barrier Region HTML Report
- An additional Line Profile Plot

This second plot is extremely important for engineering interpretation.

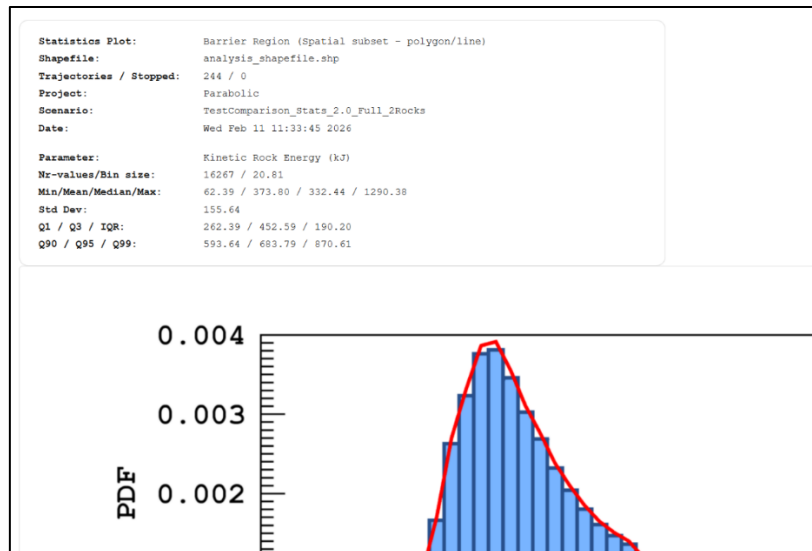


Figure 7-16: Barrier Region Report for a polygon shapefile.

What Does the Line Profile Plot Show?

The Line Profile Plot visualizes the spatial variation of results along the line. Typically, it contains:

- **Topography** (green line, right axis)
- **Jump height** values along the line
- **Data values distribution** (number of trajectory values per position)

The Data Values axis shows how many trajectories intersect the line at each location.

Why the Data Values Axis Is Critical

Quantile values (e.g. Q95) depend on sample size.

Along a line, the number of intersecting trajectories may vary significantly:

- Some segments may be intersected by **many** trajectories
- Other segments may be intersected by **only few** trajectories

If the number of data values drops below approximately 100:

- High quantiles (Q95, Q99) become increasingly unstable
- Single extreme trajectories may dominate the statistic
- The design value may be overly conservative or misleading

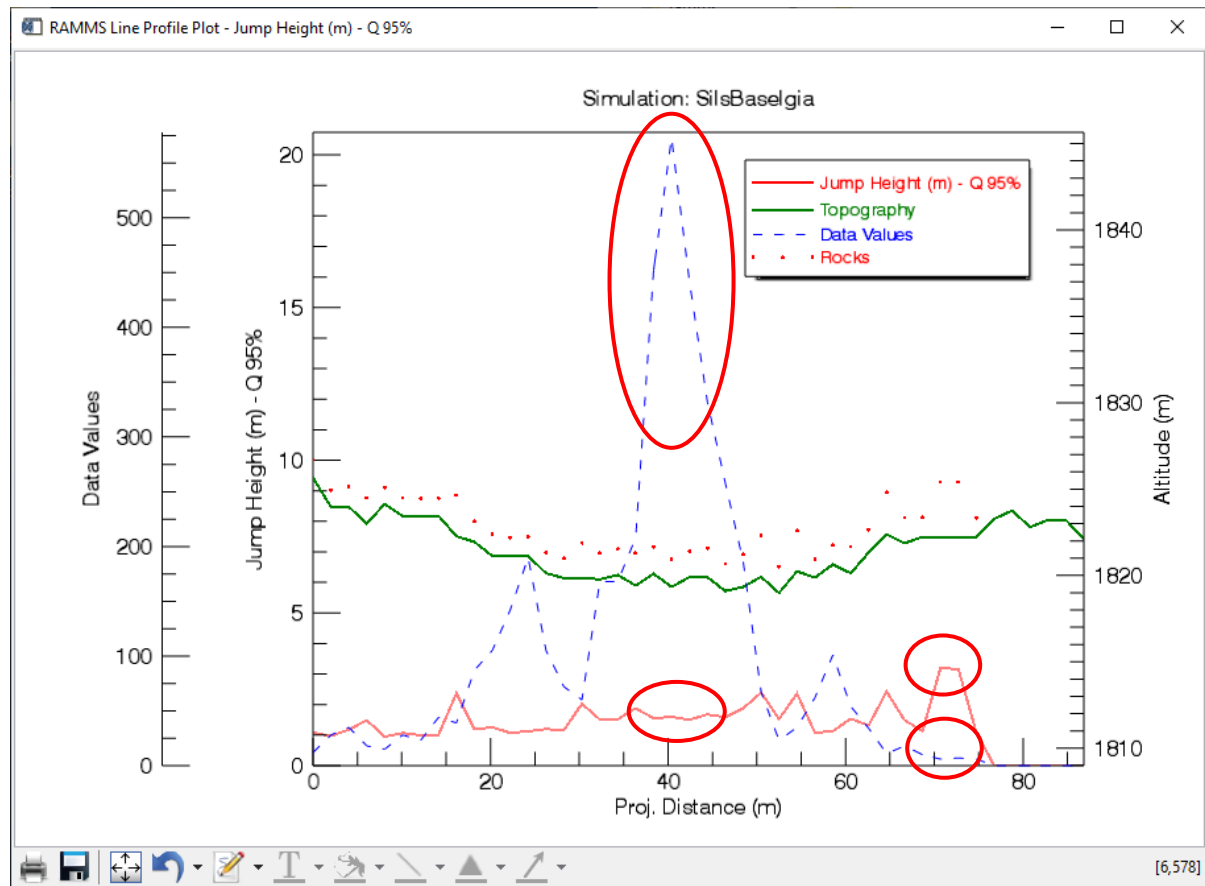


Figure 7-17: Line Profile Plot depicting the **Topography (green line, right y-axis), the jump height (rock position) on top of the topography (**red dots, Rocks**), the **Data Values** distribution (**blue** dashed line, left outer y-axis) and the **Jump Height** values (**red** line, left inner y-axis).**

This spatial information is not visible in the HTML report alone — it is only visible in the Line Profile Plot.

Engineering Interpretation Example

Consider a protection dam 80 m long.

The Line Profile Plot may show:

- Central segment: > 200 data values → stable Q95
- Edge segments: < 20 data values → highly uncertain Q95

If a very high jump height appears in a segment with only 10 data values, that value may result from a single extreme trajectory rather than typical behavior.

In such cases, the engineer should:

- Inspect trajectory paths in Trajectory Mode
- Verify whether the extreme value is physically plausible
- Consider adjusting design assumptions accordingly

When to Use Line-Based Barrier Analysis

Recommended for:

- Protection dam crest evaluation
- Road alignment checks
- Catch fence placement
- Linear infrastructure

It allows engineers to:

- Detect spatial variability of impact energy
- Identify critical segments
- Evaluate consistency of data density

Statistical Reliability Along the Line

Rule of thumb for interpreting Line Profile:

- **Data values > 200 → high reliability**
- **100–200 → acceptable**
- **50–100 → interpret carefully**
- **< 50 → high uncertainty**

High quantiles in segments with low data density must always be critically assessed.

Practical Engineering Workflow

For line-based structures:

- Generate Barrier Plot from line shapefile
- Examine Line Profile Plot
- Check Data Values distribution
- Inspect Q95 / Q99 values
- Review extreme values in Trajectory Mode if necessary

This ensures that design decisions are not based on statistically weak segments.

7.3.3 Plots: Barrier Region (Shapefile – Multiple)

Menu: **Statistics → Plots: Barrier Region (Shapefile – Multiple)**

This function allows evaluation of several shapefiles in a single workflow.

Typical use cases:

- Multiple net fields
- Several road sections
- Different dam segments
- Comparison of alternative mitigation layouts

What Happens Internally?

For each shapefile:

- Trajectory values are extracted independently
- A separate HTML report is generated
- Statistical summaries are computed individually

No mixing of regions occurs.

Engineering Benefit

This tool allows:

- Direct comparison of impact energy along multiple structures
- Identification of most critical segment
- Efficient reporting for large infrastructure projects

7.3.4 Number of Rocks

Menu: **Statistics → Nr of Rocks**

This function visualizes the number of trajectories passing through each raster cell.

Engineering Interpretation

This map shows:

- Spatial frequency of rock passage
- Preferred rockfall paths
- Concentration corridors

High values indicate:

- Main flow channels
- High exposure zones

This is particularly useful for:

- Hazard zoning
- Identifying natural catchment areas
- Preliminary mitigation placement

Important

Nr of Rocks does not provide energy information. It only quantifies trajectory frequency. High frequency does not necessarily imply high energy.

7.3.5 Number of Deposited Rocks

Menu: **Statistics → Nr of Deposited Rocks**

This function shows how many rocks stop in each raster cell.

Engineering Use

This map is useful for:

- Identifying natural deposition zones
- Designing catchment areas
- Planning debris removal
- Verifying stopping behavior

Cells with high deposition counts indicate:

- Natural accumulation zones
- Reduced residual hazard downslope

7.3.6 Reach Probabilities

Reach probability describes the likelihood that a simulated rock trajectory reaches a specified target.

Depending on the application, the target can be:

- a **raster cell** (spatially distributed results),
- a **polygon** (e.g. buildings, roads, protection structures), or
- a **target line (SOL)** (e.g. a protection line or design section).

In **RAMMS::Rockfall**, reach probabilities are primarily evaluated **per raster cell**, forming the basis for spatial hazard assessment.

Influence of Grid Resolution

The chosen grid resolution has a strong influence on the numerical values of reach probability.

- For very fine grids (cell size < 5 m), the probability that a block hits a single cell becomes very small.
- As a result, reach probabilities may be difficult to interpret.

To improve interpretability, simulations can be evaluated on a **coarser result grid**:

- Trajectories from a high-resolution simulation (e.g. 1–2 m) are mapped to a coarser grid (e.g. 5 m)
- Reach probabilities are then computed on that grid

This typically leads to more meaningful and stable probability values.

Alternative Target Definitions

In addition to cell-based evaluation, RAMMS provides alternative target definitions:

- **Polygons (shapefiles)** : probability of impact on objects such as buildings, roads, or protection structures
- **Target lines (SOL)**: probability that trajectories reach a specified line which is particularly useful for engineering design questions

Reach Probability (Source)

Menu: **Statistics → Reach Probability (Source)**

Definitions

- n_S : number of release (source) cells
- n_R : number of rock types/shapes at the source cells
- n_O : number of trajectories simulated per source cell (orientations)
- n : number of trajectories that reach the considered raster cell

- n_c : number of contributing source cells
(source cells from which at least one trajectory reaches the considered cell)

Definition of Probability

The source reach probability is defined as:

$$P_{\text{source}}(\text{cell}) = \frac{n}{n_R \cdot n_c \cdot n_O}$$

This corresponds to the ratio of:

- the number of trajectories reaching the cell, to
- the total number of trajectories released from **contributing source cells**

Interpretation

The source reach probability is **conditioned on contributing release areas**:

- Only source cells that are capable of reaching the target cell are considered
- Release areas with no influence on the cell are excluded

This isolates the effect of specific release zones on the reach probability.

Engineering Use

- Evaluating particular unstable zones
- Comparing release scenarios
- Hazard source attribution

Reach Probability (Total)

Menu: **Statistics → Reach Probability (Total)**

Definition of Probability

The total reach probability is defined as:

$$P_{\text{total}}(\text{cell}) = \frac{n}{n_R \cdot n_S \cdot n_O}$$

This corresponds to the ratio of:

- the number of trajectories reaching the cell, to
- the total number of trajectories released from **all source cells**

Difference from Source Reach Probability

- **Total reach probability** → based on all source cells (n_S)
- **Source reach probability** → conditioned on contributing source cells (n_C)

Engineering Use

Total reach probability is often used for:

- **Hazard mapping**
- **Zonation**
- **Risk modelling inputs**

Reach Probability from Shapefile

Menu: **Statistics → Reach Probability from Shapefile**

Definitions

- $n_{intersect}$: number of trajectories intersecting the polygon

Analogous to the raster-based definition, a source-conditioned probability can be defined as:

$$P_{\text{source, polygon}} = \frac{n_{\text{intersect}}}{n_R \cdot n_C \cdot n_O}$$

This corresponds to the ratio of:

- the number of trajectories intersecting the polygon, to
- the total number of trajectories released from **contributing source cells**

The “normal” reach probabilities (Total and Source Reach Probability) are calculated **per grid cell**. This may yield lower probabilities than expected, especially for very fine grids or for small objects (e.g. buildings, road sections) that cover only a few cells.

With the *Reach Probability from Shapefile* option, it is possible to calculate a **Source Reach Probability for a polygon region**. The polygons are read from a shapefile (e.g. building footprints, road segments, protection objects), and the probability is evaluated for the entire polygon instead of individual cells.

7.3.7 Probability of reaching Target Line (SOL)

Menu: **Statistics → Probability of reaching Target Line (SOL)**

Concept and Motivation

The **SOL-analysis** evaluates how many simulated rockfall trajectories **reach and cross a user-defined line** in the terrain.

The **target line (SOL)** represents an element at risk such as a:

- road
- railway
- protection fence
- infrastructure corridor

In German, the SOL corresponds to a “**Schadenobjektlinie**” (damage-object line).

This analysis is particularly useful when the objective is to **quantify the exposure of linear infrastructure** and to verify whether protective measures are correctly positioned.

Definition of the SOL

The SOL is defined as a **polyline shapefile** in the model domain. This line/area shapefile must be specified by the user before executing **Statistics → Probability of reaching Target Line (SOL)**. A window appears (Figure 7-18) with an overview file of the probability. A trajectory is counted as *reaching the SOL* if it **intersects or crosses the line**. Each segment of the line is evaluated independently, allowing for **spatially resolved results along the infrastructure**.

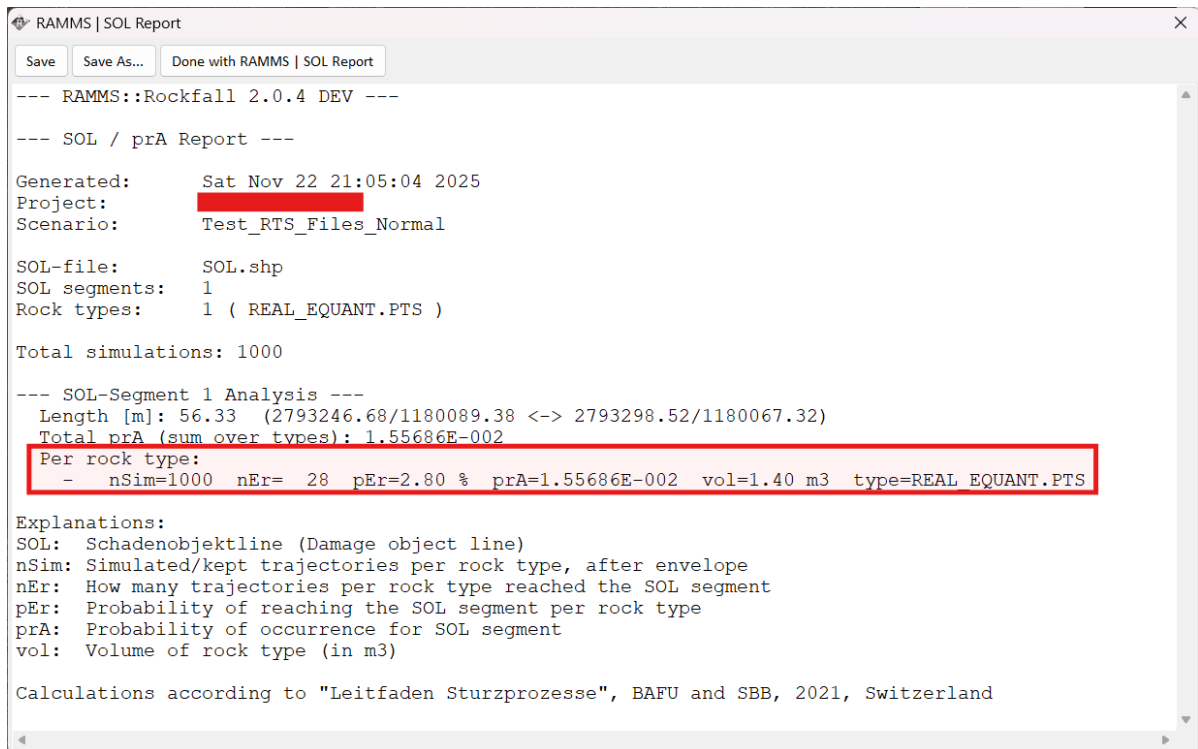


Figure 7-18: Result of SOL-Analysis

Mathematical Formulation

Let:

- n_{Sim} = total number of simulated trajectories
- n_{Er} = number of trajectories reaching (crossing) the SOL

Reach Probability

The probability that a rock reaches the target line is defined as:

$$p_{\text{Er}} = \frac{n_{\text{Er}}}{n_{\text{Sim}}}$$

Spatial Impact Probability (line-based intensity)

To describe how impacts are distributed along the target line:

$$p_{\text{rI}} = \frac{n_{\text{Er}} \cdot \sqrt[3]{V}}{L}$$

where:

- V = rock volume
- L = length of the SOL segment

This quantity represents a **spatially normalized impact intensity** along the line.

Probability of Occurrence

The probability of occurrence combines reach probability and spatial impact:

$$p_{rA} = p_{rI} \cdot p_{Er} = \frac{n_{Er}^2 \cdot \sqrt[3]{V}}{L \cdot n_{Sim}}$$

This represents the **joint probability of a rock reaching the line and contributing to impact intensity**.

Interpretation of the Probabilities

- p_{Er} → Will a rock reach the line? (exposure)
- p_{rI} → Where and how concentrated are impacts along the line? (spatial intensity)
- p_{rA} → Overall likelihood of hazardous impact along the line (risk input)

Additionally, the trajectories found by this feature can then be opened in Trajectory-Mode.

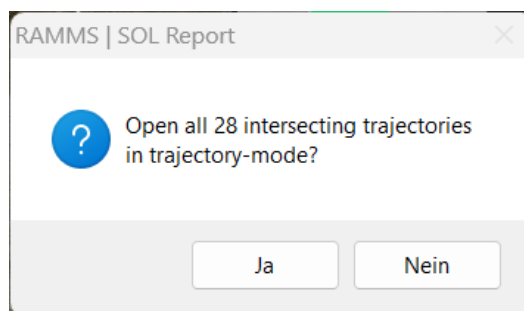


Figure 7-19: Open found trajectories in Trajectory-Mode

Engineering Applications

The SOL-analysis can be used to:

- **Verify alignment of protective structures**
(e.g. check if a barrier or ditch is correctly positioned)
- **Compare scenarios or rock types**
(e.g. different block sizes or release areas)
- **Provide input for hazard and risk assessments**
(e.g. crossing probability for infrastructure)

7.3.8 JumpH vs KinEnergy Plot for Target Line

Menu: **Statistics → JumpH vs KinEnergy Plot for Target Line**

This analysis tool provides a simple way to visualize the **impact energy and jump height** of rock trajectories along a line shapefile.

Each dot in the plot represents one **rock trajectory** recorded at the analysis location:

- **Y-axis – Jump Height (m):**
The rock's jump when crossing the line shapefile.
- **X-axis – Kinetic Energy (kJ):**
The kinetic energy of the rock at that same point.

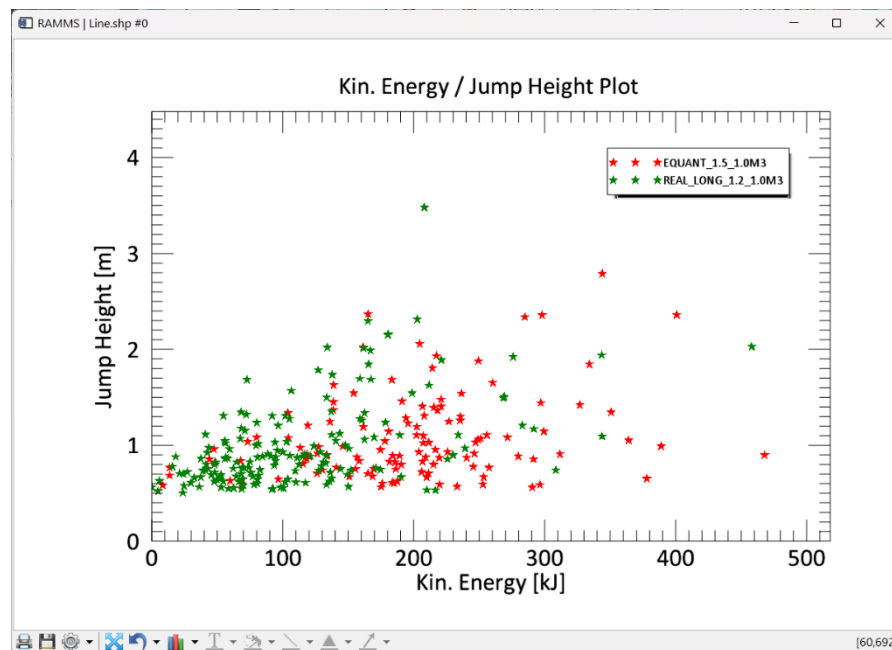


Figure 7-20: Window showing all trajectories with color-coded rock types

Different **rock types** are shown in **different colors**, making it easy to compare their behavior in one view.

Interpreting the Plot

The plot shows how energetic the rocks are relative to their jump heights:

- Rocks in the **lower-left region** (low energy, low jump height) indicate low-risk impacts.
- Points toward the **upper-right** indicate high kinetic energy and large jumps, i.e., potentially critical impacts.

Outputs

For each analysis:

- A **plot** window showing all trajectories with color-coded rock types.
- A **CSV file** containing the raw data (jump height, kinetic energy, filename) for further analysis or reporting.

7.3.9 Open Trajectories from Shapefile

Menu: **Statistics → Open Trajectories from Shapefile**

Use this feature to select a shapefile (polygon or polyline) and open all the trajectories (passing or stopping in the specified shapefile) in **Trajectory Mode**.

7.4 Trajectory Mode

To analyze simulation results in more detail, the rocks can be opened in *Trajectory Mode*. This mode enables a detailed analysis of single trajectories of specific rocks. No statistic is available in *Trajectory Mode*.

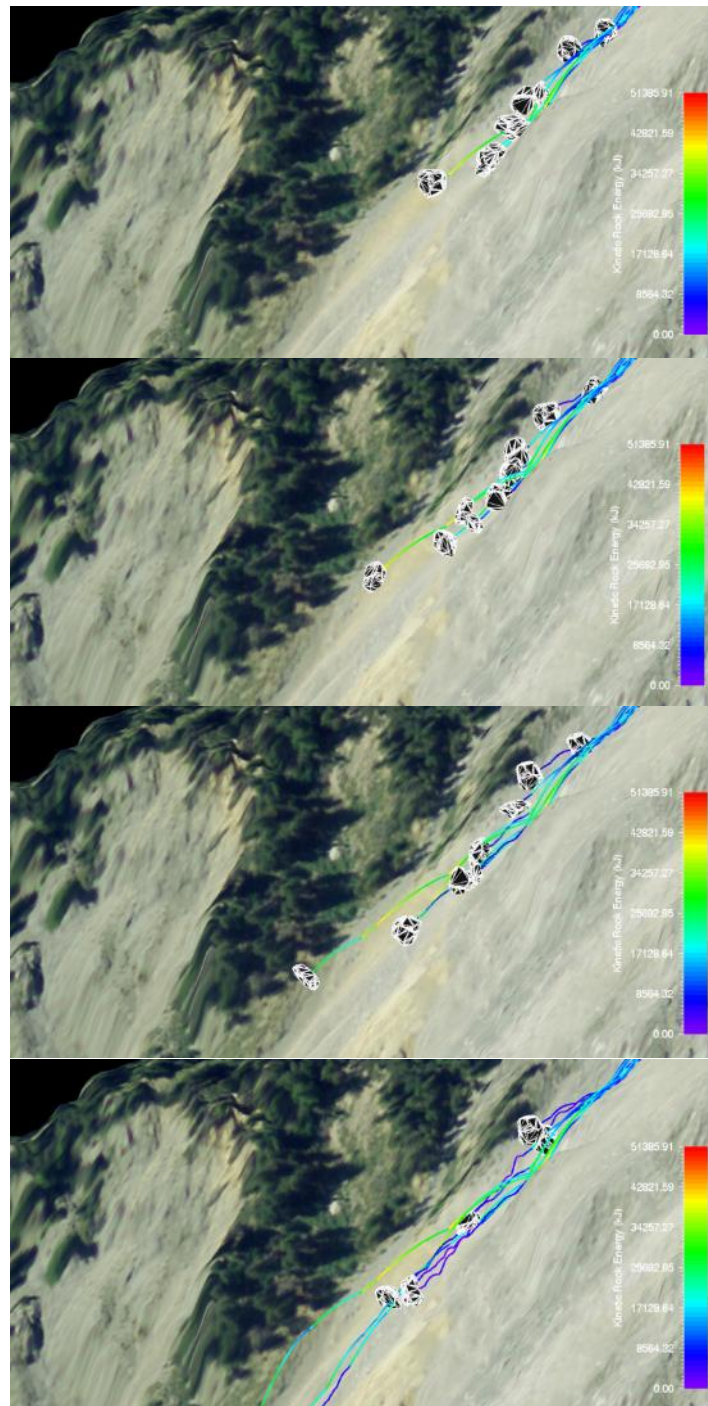


Figure 7-21: Rockfall trajectories; different colors depict different kinetic rock energies (KJ).

7.4.1 Open results in Trajectory Mode

Open trajectories with the button **T** the keyboard combination **Ctrl+T** or go to **Track** → **Open** → **Rockfall Trajectories**. Choose the trajectories that you are interested in from the *traj_files* folder in the *output* scenario folder and click **Open**.

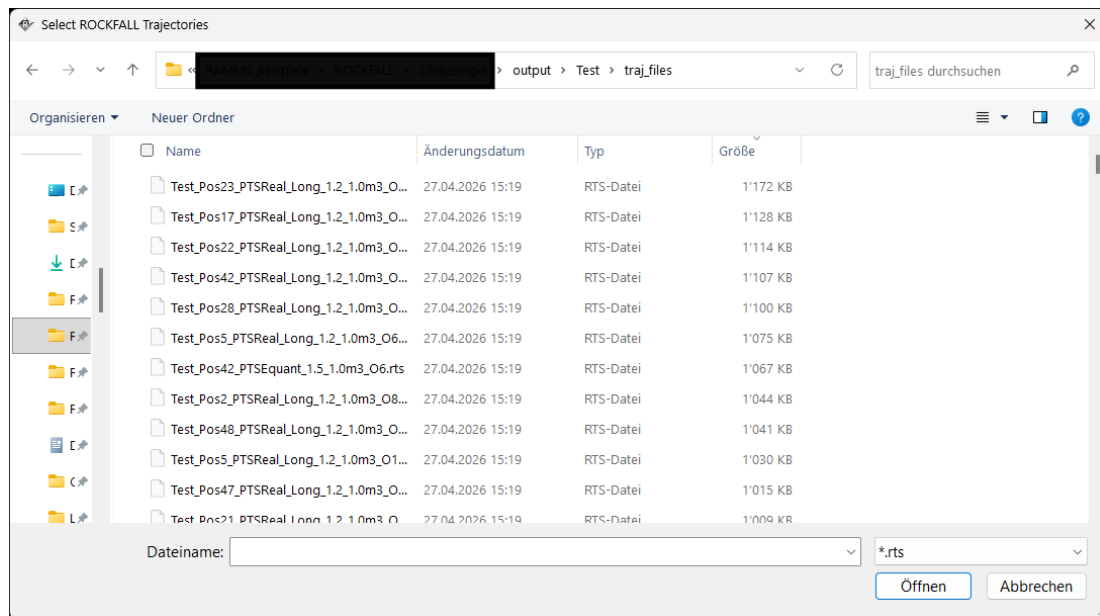


Figure 7-22: Open trajectories dialog window

RAMMS will then open all the selected trajectories. If you want to add trajectories from another scenario, or filter your output files, then use **Track** → **Open** → **Rockfall Trajectories (Filter/Multi)**. In Figure 7-23 you could filter your selected trajectories (use a colon to use multiple filter strings). Otherwise click **OK**.

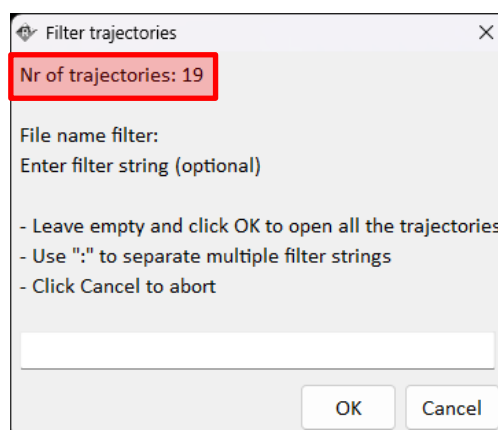


Figure 7-23 Filter options for selected trajectories

Add trajectories from other scenarios (but within the same project). Click **Yes** in Figure 7-24 to select more trajectories, click **No** otherwise.

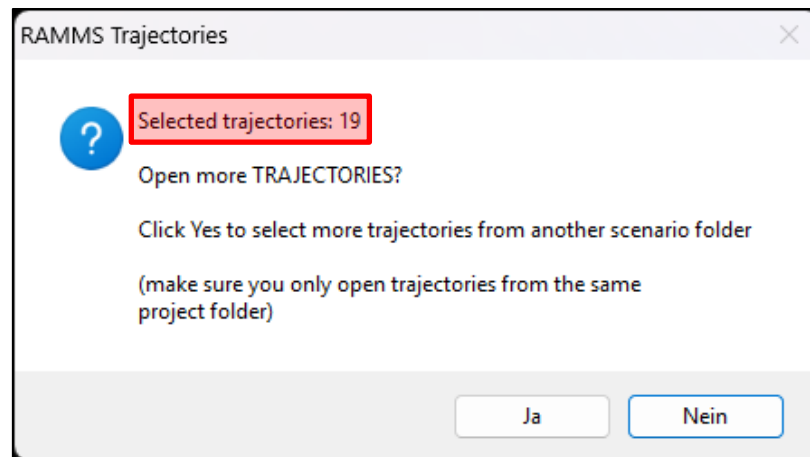


Figure 7-24 Possibility to add trajectories from another scenarios.

It is suggested to open only up to 100 single trajectories at one time (e.g. from a specific scenario). Although it is possible to open more trajectories, it is not recommended, because the memory usage will increase strongly, and the handling of your visualization will get very slow. Control if the trajectory mode is ON (in the general tab of the right field) and the toolbar shows the number of trajectories.

The buttons **H** **V** **E** provide quick access to Jump Height, Velocity and Kinetic Rock Energy of the simulation.

7.4.2 Visualize different parameters

The drop-down menu **Results** offers the following functions in the trajectory mode:

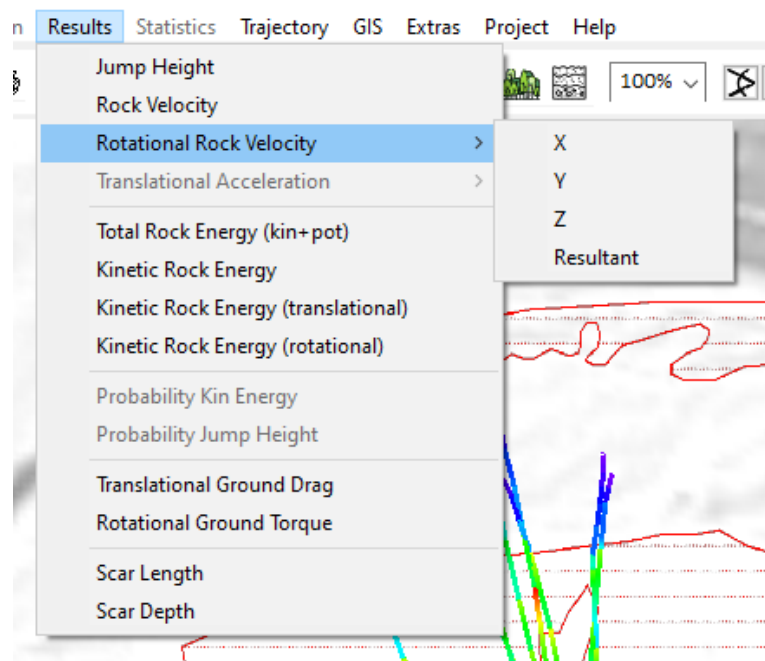


Figure 7-25: Trajectory Mode: Dropdown menu Results

- Jump Height (m)

- **Rock Velocity (m/s)**
- **Rotational Rock Velocity → X, Y, Z, Resultant (rad/s, deg/s or rot/s)** (the unit of rotation can be adjusted in Additional Preferences, ROT_UNIT, default rotation unit is rot/s)
- **Total Rock Energy (kin + pot) (kJ)**
- **Kinetic Rock Energy (kJ)**
- **Kinetic Rock Energy (translational) (kJ)**
- **Kinetic Rock Energy (rotational) (kJ)**
- **Translational Ground Drag (kN)**
- **Rotational Ground Torque (kNm)**
- **Scar Slippage (m)**
- **Scar Depth (m)**

Exercise 7.1a: Displaying calculation values.

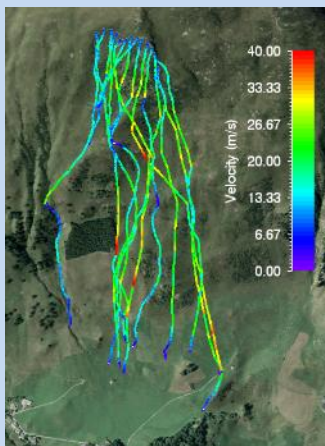


Figure 7-26: Results Velocity

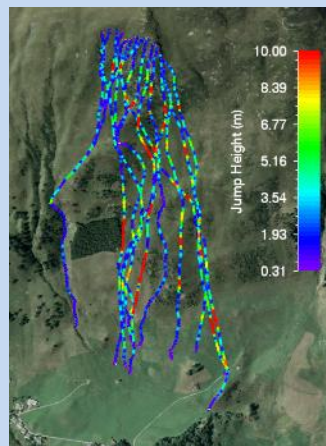


Figure 7-27: Results Jump Height

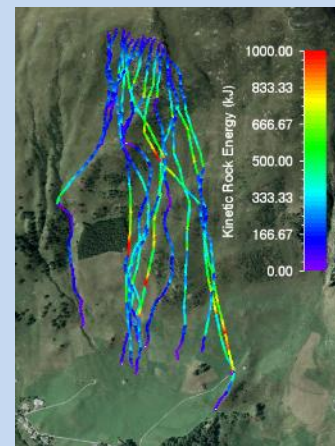


Figure 7-28: Results Kinetic Rock Energy

The values of **Jump Height**, **Rock Velocity** and **Kinetic Rock Energy** (Figure 7-26 - Figure 7-28) give a good overview of the dimension of the rockfall event in the trajectory mode. You can choose the parameters in the horizontal toolbar under **Results**.

7.4.3 Working with trajectories

Select a trajectory with the mouse:

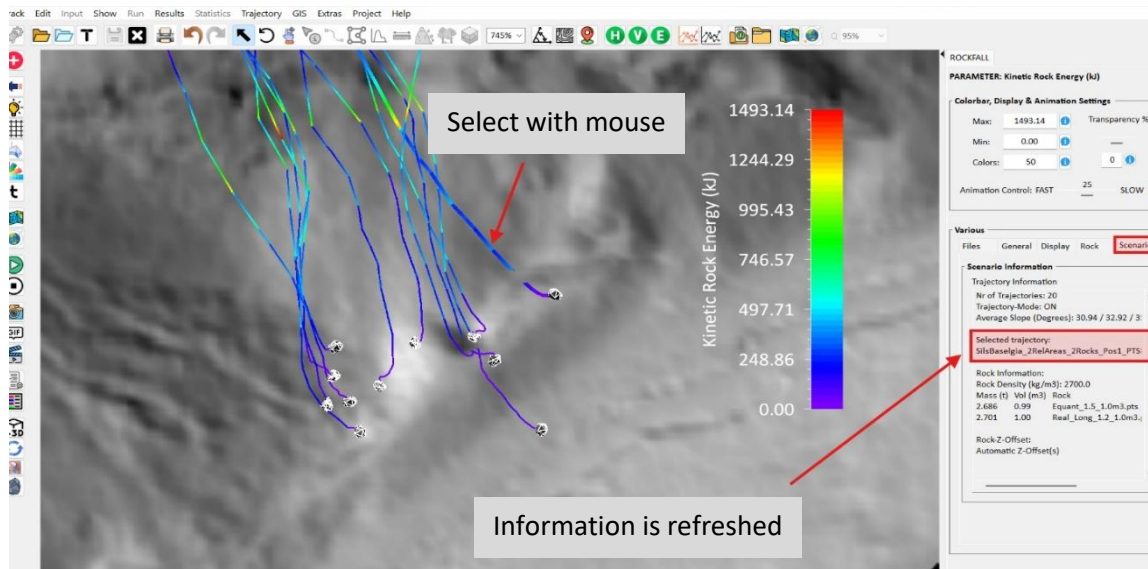


Figure 7-29: Trajectory information – General tab. The information (filename, start position of trajectory, etc.) is refreshed in the General tab on the right side. Additionally, the Rock tab indicates the rock used for the selected trajectory (see next figure).

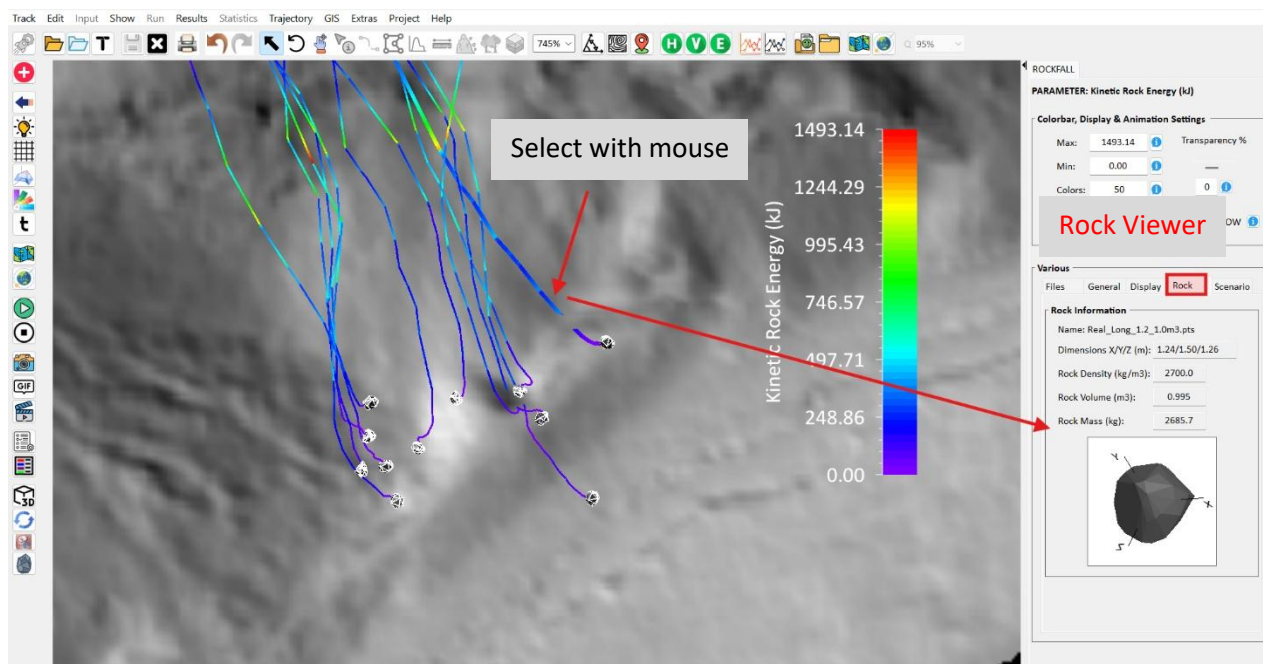


Figure 7-30: Trajectory information – Rock tab.

The menu **Trajectory** offers the following functions:

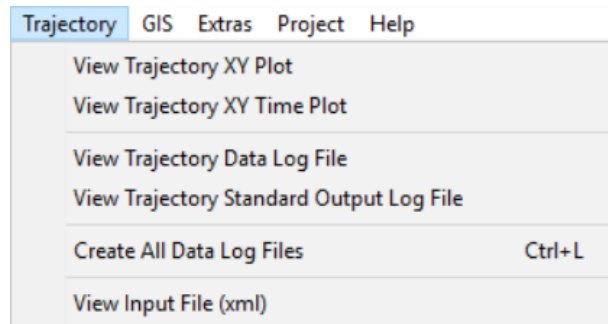


Figure 7-31: Trajectory Mode: Menu Trajectory.

- View Trajectory XY Plot
- View Trajectory XY Time Plot
- View Trajectory Data Log File
- View Trajectory Standard Output Log File
- Create All Data Log Files
- View Input File (xml)

In the horizontal toolbar you can find the following functions:

- Rock Trajectory XY Plot 
- Rock Trajectory XY Time Plot 
- Line Profile 

7.4.4 Rock Trajectory XY Plot

Click on a rock trajectory. You can find the function *View Trajectory XY Plot* in the horizontal toolbar (button ) or in the menu **Trajectory** → **View Trajectory XY Plot**. If you want to analyze a trajectory in detail, the XY plot of a trajectory is the way to go. The graph shows the currently active parameter (you can change it by clicking one of the buttons in the upper horizontal toolbar  or by selecting another result parameter via the **Results** menu). You can keep the *Trajectory XY Plot* by saving it, see Exercise 5.2b below “How to create a Trajectory XY Plot”.

Exercise 7.1b : How to create a Trajectory XY Plot

- Switch to 2D mode by clicking 
- Activate the project by clicking on it once. Then click on the specific rock trajectory you want to plot.
- Go to **Trajectory** → **View Trajectory XY Plot** or click 

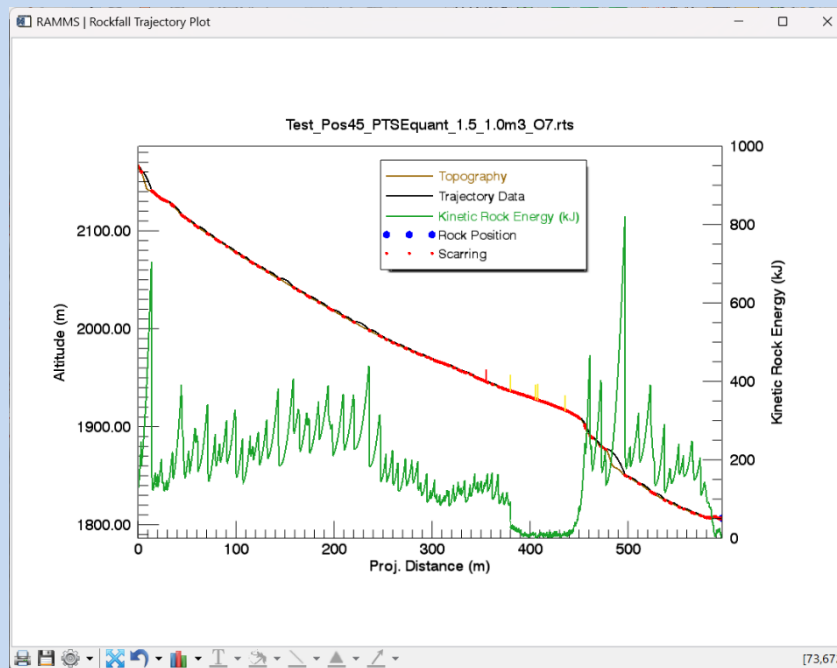


Figure 7-32: Trajectory XY Plot.

- A window opens, displaying the **Trajectory XY Plot**.
- You can save, print and modify the plot with the tools in the upper toolbar or open another plot.

Plot explanations:

- Brown line: terrain surface (scale on the left side).
- Black line: rock trajectory added to the terrain surface (altitude in m a.s.l., scale on the left side).
- Green line: active parameter (scale on the right side).
- Blue dot: current rock position (according to the dump step shown in your simulation).
- Red dots: points of contact/scarring (consider the time step of your simulation – missing contact points are possible if time steps are too large).
- Bottom scale: projected profile distance (m).

7.4.5 Line profile

Go to **Extras** → **Profile...** → **Draw Line Profile** or click  to draw a line profile. The line profile function provides a graph of the currently active parameter along a specific line through the rockfall area. This is helpful when it is of interest to know the values and maximum values at these places (e.g. close to a road or dam). Line profiles are saved in the file *profile.txt* in the project directory. If you want to keep a line profile, you have to save it, see Exercise 7.1c "How to draw a line profile".

Exercise 7.1c : How to draw a line profile

(1) Draw a new line profile:

- Switch to 2D mode by clicking .
- Activate the project by clicking on it once, then click  or choose **Extras** → **Profile...** → **Draw New Line Profile**.
- Define the line profile in the same way you specify a new release line (see Exercise 5.2b "How to create a new release line"). Finish the line profile with a right-click on the mouse button.

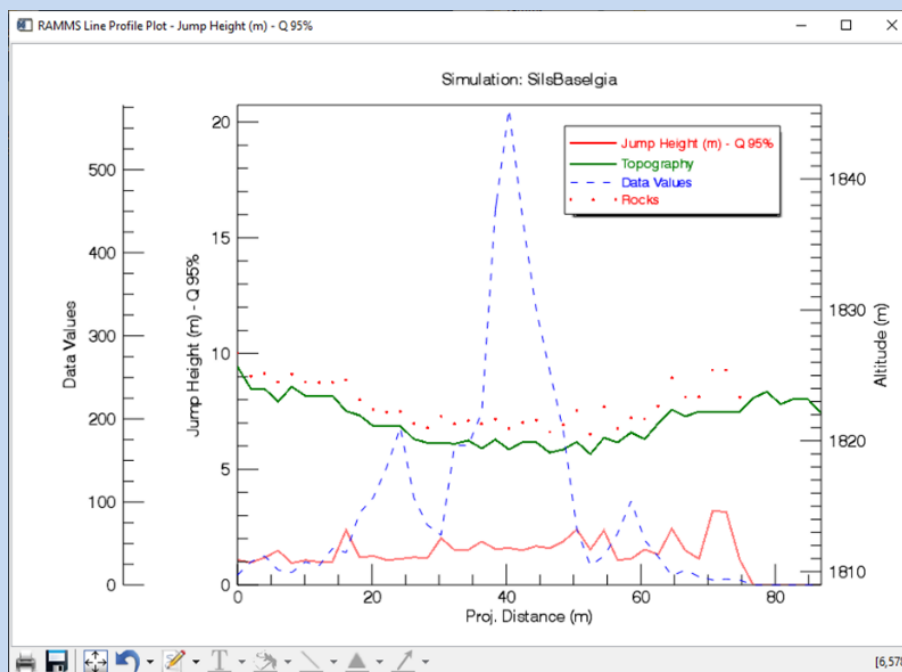


Figure 7-33: Line Profile Plot

- A window opens (Figure 7-33), displaying the **Line Profile**.

Plot explanations:

- **Green line:** track profile (altitude, y-axis on the right side).
- **Red dots:** active parameter (rock position) on top of the topography (altitude, y-axis on the right side).
- **Red line:** active parameter (inner y-axis on the left side).
- **Blue dashed line:** the *Data Values* distribution.
- Bottom x-axis: projected profile distance (m).

If you change the active parameter or the *Min* and *Max* values in the *Display* tab in RAMMS, the plot will be directly updated.

- To save the coordinates of the points belonging to the line profile, select **Extras → Profile... → Save Line Profile Points** and enter a file name.
- To save the line profile parameter's data (distance (m) and the active parameter, e.g. the jump height (m)) at the current dump step, select **Extras → Profile... → Export Line Profile Plot Data** and enter a file name.

(2) Load an existing line profile:

- Switch to 2D mode by clicking .
- Activate the project by clicking on it once, then click  or choose **Extras → Profile... → Draw New Line Profile**.
- Click the *middle mouse button* once.
- A window pops up and you can browse for the line profile you wish to open.

7.4.6 Trajectory Data Log File

To see the exact values of a rockfall trajectory, check the *Trajectory Data Log File* which shows the results for every dump step of a single trajectory. Click on a rock trajectory in the trajectory mode and go to **Trajectory → View Trajectory Data Log File** to open it.

Rock type: 2 (0: Sphere, 1: Cuboid, 2: Rock)
pts-file: C:\Users\...\Real_Equant_1.4.pts

Selected trajectory: C:\Users\...\output\Test_RTS_Files_Normal\traj_files\Test_RTS_Files_Normal_Pos1_PTS

t (s)	x (m)	y (m)	z (m)	p0 (l)	p1 (l)	p2 (l)	ξ
0.000	2793296.700	1180256.300	2359.697	0.137	0.465	-	-
0.002	2793296.700	1180256.300	2359.697	0.137	0.465	-	-
0.020	2793296.700	1180256.300	2359.695	0.137	0.465	-	-
0.040	2793296.700	1180256.300	2359.689	0.137	0.465	-	-
0.060	2793296.700	1180256.300	2359.679	0.137	0.465	-	-
0.080	2793296.700	1180256.300	2359.665	0.137	0.465	-	-
0.100	2793296.700	1180256.300	2359.647	0.137	0.465	-	-
0.120	2793296.700	1180256.300	2359.625	0.137	0.465	-	-
0.140	2793296.700	1180256.300	2359.599	0.137	0.465	-	-
0.160	2793296.700	1180256.300	2359.570	0.137	0.465	-	-
0.180	2793296.700	1180256.300	2359.536	0.137	0.465	-	-
0.200	2793296.700	1180256.300	2359.499	0.137	0.465	-	-
0.220	2793296.700	1180256.300	2359.457	0.137	0.465	-	-
0.240	2793296.700	1180256.300	2359.412	0.137	0.465	-	-
0.260	2793296.700	1180256.300	2359.363	0.137	0.465	-	-
0.280	2793296.700	1180256.300	2359.310	0.137	0.465	-	-
0.300	2793296.700	1180256.300	2359.253	0.137	0.465	-	-
0.320	2793296.700	1180256.300	2359.192	0.137	0.465	-	-
0.340	2793296.700	1180256.300	2359.127	0.137	0.465	-	-
0.360	2793296.700	1180256.300	2359.058	0.137	0.465	-	-
0.380	2793296.700	1180256.300	2358.985	0.137	0.465	-	-
0.400	2793296.700	1180256.300	2358.908	0.137	0.465	-	-
0.420	2793296.700	1180256.300	2358.828	0.137	0.465	-	-
0.440	2793296.700	1180256.300	2358.743	0.137	0.465	-	-
0.460	2793296.700	1180256.300	2358.655	0.137	0.465	-	-
0.480	2793296.700	1180256.300	2358.562	0.137	0.465	-	-
0.500	2793296.700	1180256.300	2358.466	0.137	0.465	-	-
0.520	2793296.700	1180256.300	2358.366	0.137	0.465	-	-
0.540	2793296.700	1180256.300	2358.261	0.137	0.465	-	-
0.560	2793296.700	1180256.300	2358.153	0.137	0.465	-	-
0.580	2793296.700	1180256.300	2358.041	0.137	0.465	-	-
0.600	2793296.700	1180256.300	2357.925	0.137	0.465	-	-
0.620	2793296.700	1180256.300	2357.827	0.116	0.467	-	-
0.640	2793296.700	1180256.300	2357.750	0.071	0.472	-	-

Figure 7-34: Trajectory Data Log File.

7.4.7 Create All Data Log Files

Select **Trajectory -> Create All Data Log Files** or hit the combination **Ctrl+L** to create data log files for all currently opened trajectories. These data log files are the same as described in Figure 7-34 and will be saved in **../ProjectDirectory/output/ScenarioDirectory/data**. Note that depending on the amount of opened trajectories, generating all log files could take some time and use a lot of disk space.

7.4.8 Trajectory Input File

The input file is a simple xml file and can be viewed from within RAMMS. Use **Trajectory** → **View Input File (xml)** to open a selected trajectory's input file.

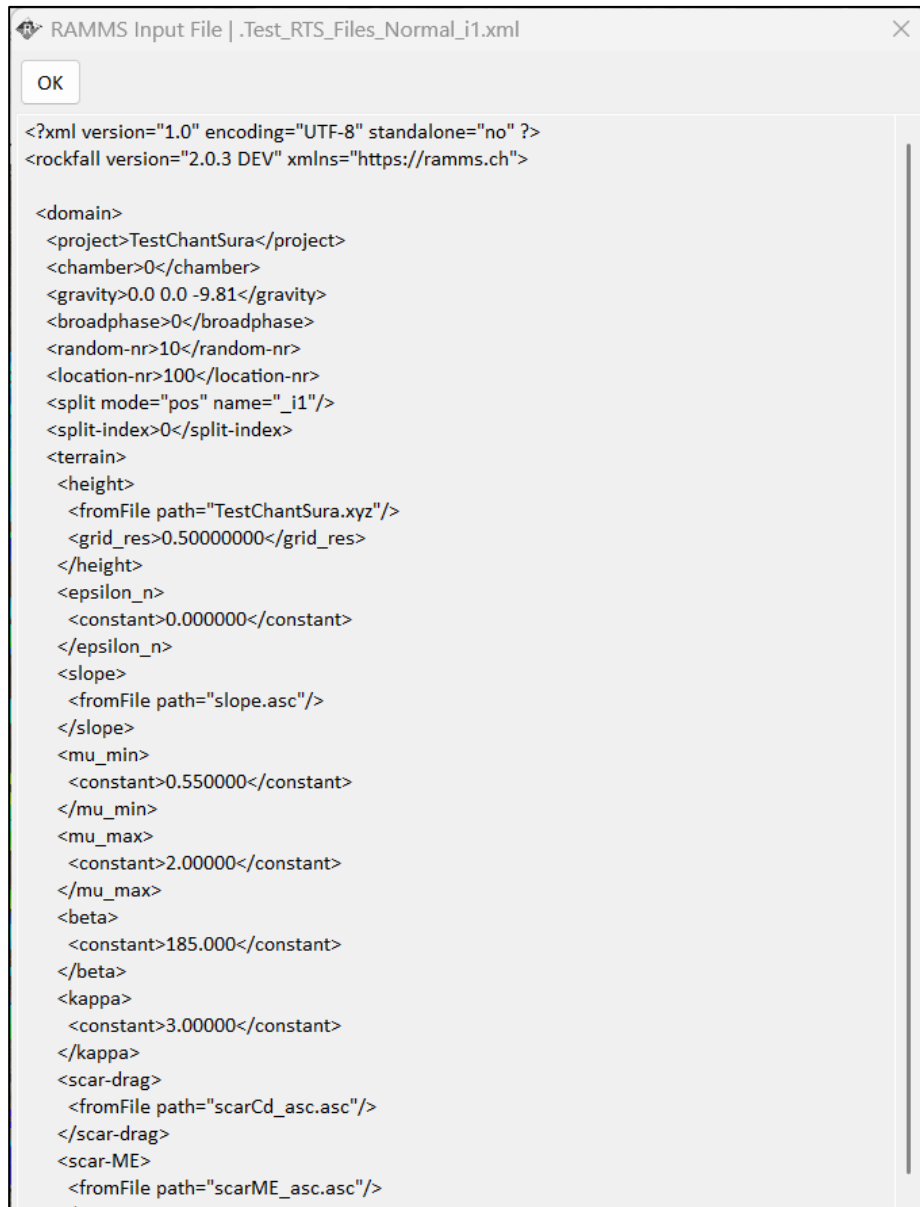


Figure 7-35: Trajectory Input File.

7.4.9 Rock trajectory animation

It is possible to start an animation of all trajectories. Switch to 3D mode by clicking  (2D mode is working as well).

- Start the animation (Alternative: F8) 
- Pause the animation (Alternative: F8) 
- Stop/Restart the animation (Alternative: F9) 

Change the speed of the animation in the *Display* tab on the right side (speed slider from fast to slow, in frames per second).

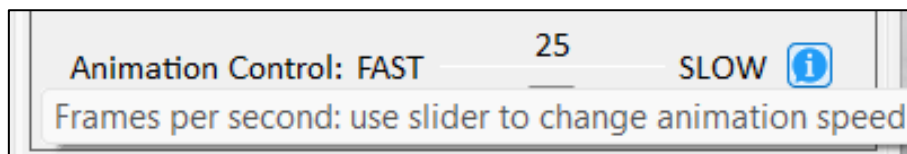


Figure 7-36: Animation speed control slider.

7.5 Impact Analysis (Terrain or Obstacles)

7.5.1 Impact Analysis: Rockfall Sheds (from pts, ASTRA)

Menu: Results → Impact Analysis: Rockfall Sheds (from pts, ASTRA)

This analysis is meant for rockfall sheds and is based on the following Swiss-guidelines “Effects of rockfall on protective sheds” (ASTRA-Richtlinie 12006: [Einwirkungen infolge Steinschlags auf Schutzgalerien](#)). According to the guidelines we can calculate the force at the point of impact F_k (kN) as well as the penetration depth t (m) according to these equations:

$$F_k = 2,8 \cdot e^{-0,5} \cdot r^{0,7} \cdot M_{E,k}^{0,4} \cdot \tan \varphi_k \cdot \left(\frac{m_k \cdot v_k^2}{2} \right)^{0,6}$$

$$t = \left(\frac{m_k \cdot v_k^2}{F_k} \right)$$

Figure 7-37: Equations to calculate force F_k and penetration depth t .

Using the following parameters:

- **Rock mass m_k (from simulation)**
- **Radius r of the rock's surrounding sphere (m) (from simulation)**
- **Impact velocity v_k (m/s) (from simulation)**

- Layer thickness of covering e [m] (manual input)
- Static compression modulus of material $M_{E,k}$ (kN/m²) (fcan be changed)
- Friction angle of covering material φ_k (°) (manual input)
- Density of rock ρ (kg/m³) (can be changed)

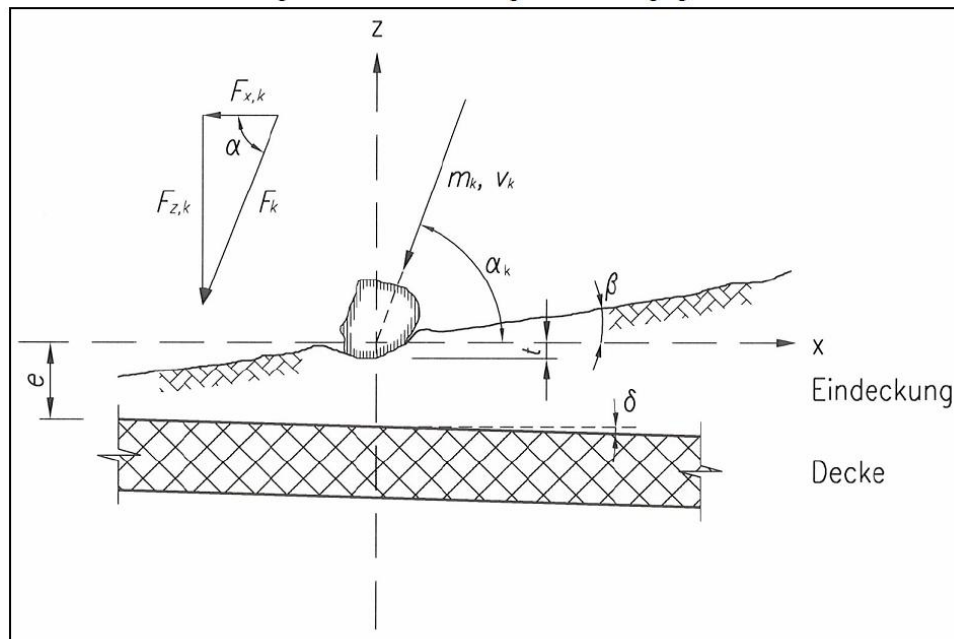


Figure 7-38: Oblique impact of rock on shed roof.

RAMMS::Rockfall will then show the following window, where the “manual input” parameters from above can be adopted. Click **Save** (if you changed values) and **Done with** to continue.

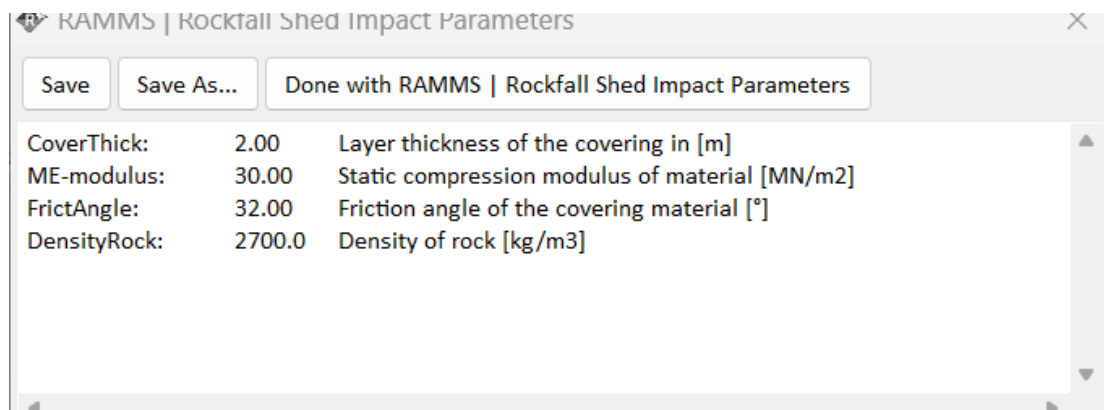


Figure 7-39: Input window for gallery-analysis parameters.

If the domain contains more than one obstacle file, the user will be requested to input the number of the obstacle, before selecting the mechanical parameters:

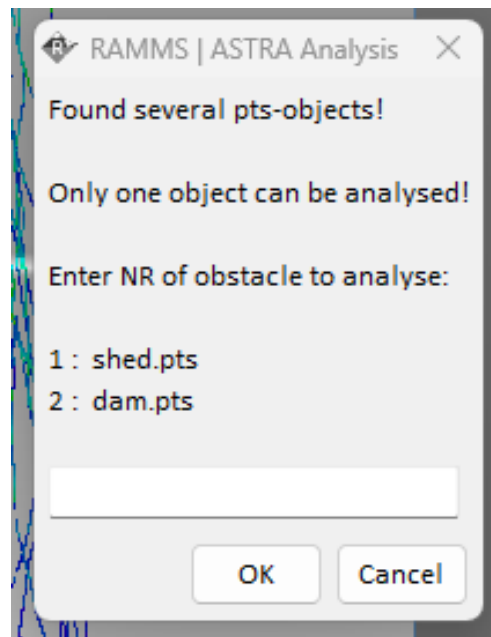


Figure 7-40: If the domain contains more than one obstacle, the user is requested to identify the obstacle for the ASTRA analysis.

RAMMS will then create a html-report of your shed impact analysis, with the most important results (statistical plots). RAMMS will use the main window of your visualization for the title image of the html-report.

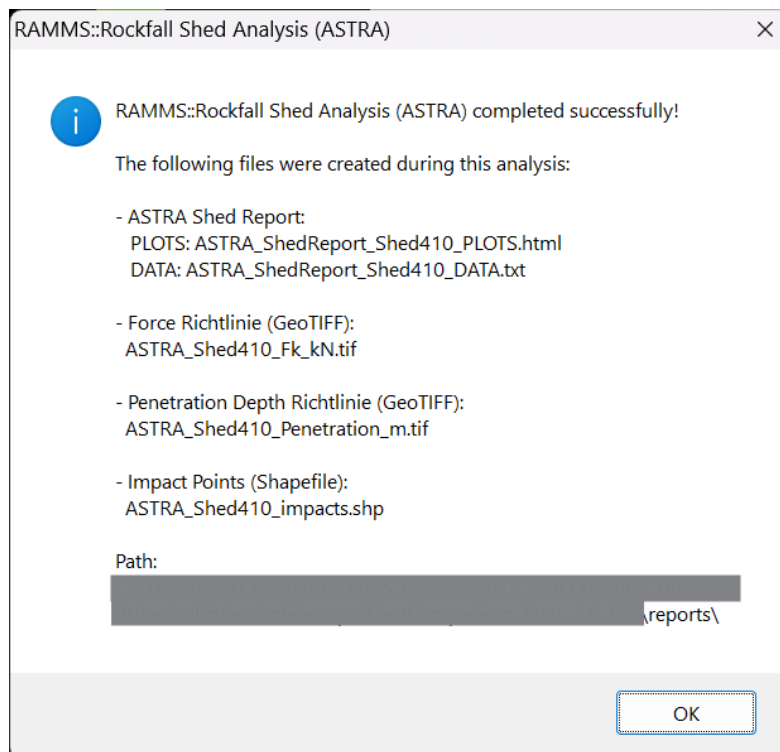


Figure 7-41: ASTRA Shed-Analysis

The following files will be created:

- ASTRA_ShedReport_<obstacle_name>_PLOTS.html: Statistical plots of impact analysis
- ASTRA_ShedReport_<obstacle_name>_DATA.txt: All data for statistical plots.
- ASTRA_<obstacle_name>_Fk_kN.tif: GeoTIFF file of distribution of impact-Force Fk (by Richtlinie) over shed-area (linear interpolation).
- ASTRA_<obstacle_name>_Penetration_m.tif: GeoTIFF file of distribution of penetration-depth (by Richtlinie) over gallery-area (linear interpolation).
- ASTRA_<obstacle_name>_impacts.shp: Point-Shapefile containing all impact-points with key attributes (impact force, angle, speed, etc.)

Remarks:

- Only the FIRST impact of each rock trajectory on the rockfall shed is used for the analysis (assumption: subsequent impacts are less severe).



Figure 7-42: Point-shapefile with impact points on gallery.

- Additionally, RAMMS creates two raster files (GeoTIFF, linear interpolation):
 - Distribution of Impact-Force Fk (by Richtlinie) over gallery-area
 - Distribution of penetration-depth (by Richtlinie) over gallery-area

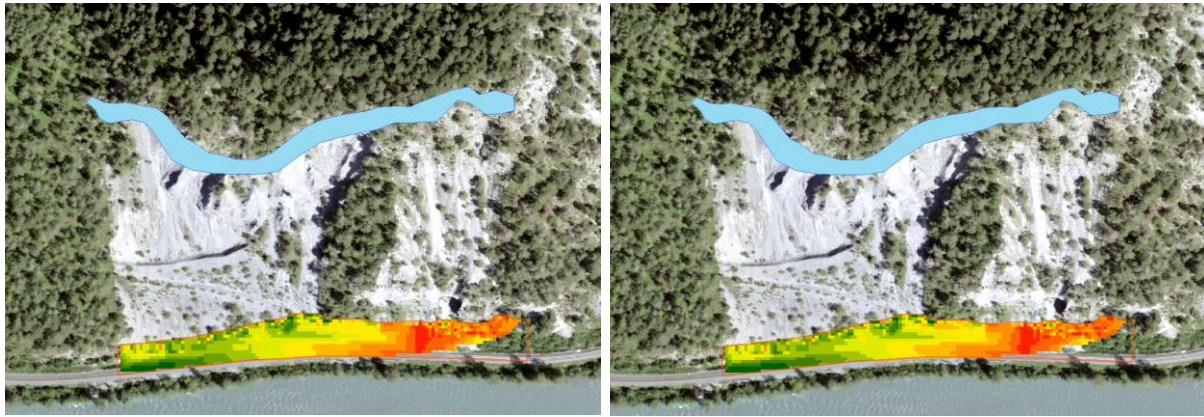


Figure 7-43: Raster results of impact force F_k (left) and penetration depth t (right).

- The GeoTIFF (ASTRA_<obstacle_name>_Fk_kN.tif, ASTRA_<obstacle_name>_Penetration_m.tif) and point shape (ASTRA_<obstacle_name>_impacts.shp) files are designed to be read by GIS software and not RAMMS.

7.5.2 Impact Analysis: Barrier/Dam/Shed (from pts)

Menu: **Results** → **Impact Analysis: Barrier/Dam/Shed (from pts)**

If you want to evaluate how rocks interact with obstacles (rockfall nets, dams, etc.), use the **Impact Analysis: Barrier/Dam/Shed (from pts)** tool.

For each obstacle (one **pts-file**), the tool:

1. Identifies **all rocks that hit this obstacle**.
2. For each rock, finds the **first impact** on that obstacle.
3. Extracts the key kinematic quantities at that moment.
4. Creates a **html-report per pts-file** of your impact analysis, with the most important results (statistical plots).
5. Writes one **CSV file per pts-file**, containing one line per rock (first hit only).

The following files are created:

- ObstacleImpact_<obstacle_name>_PLOTS.html: Statistical plots for kin. Energy (pre-impact) and impact angle.
- ObstacleImpact_<obstacle_name>_DATA.csv: Complete data of impact analysis (location, kin. Energies, velocities, impact angle, rock mass and trajectory name)

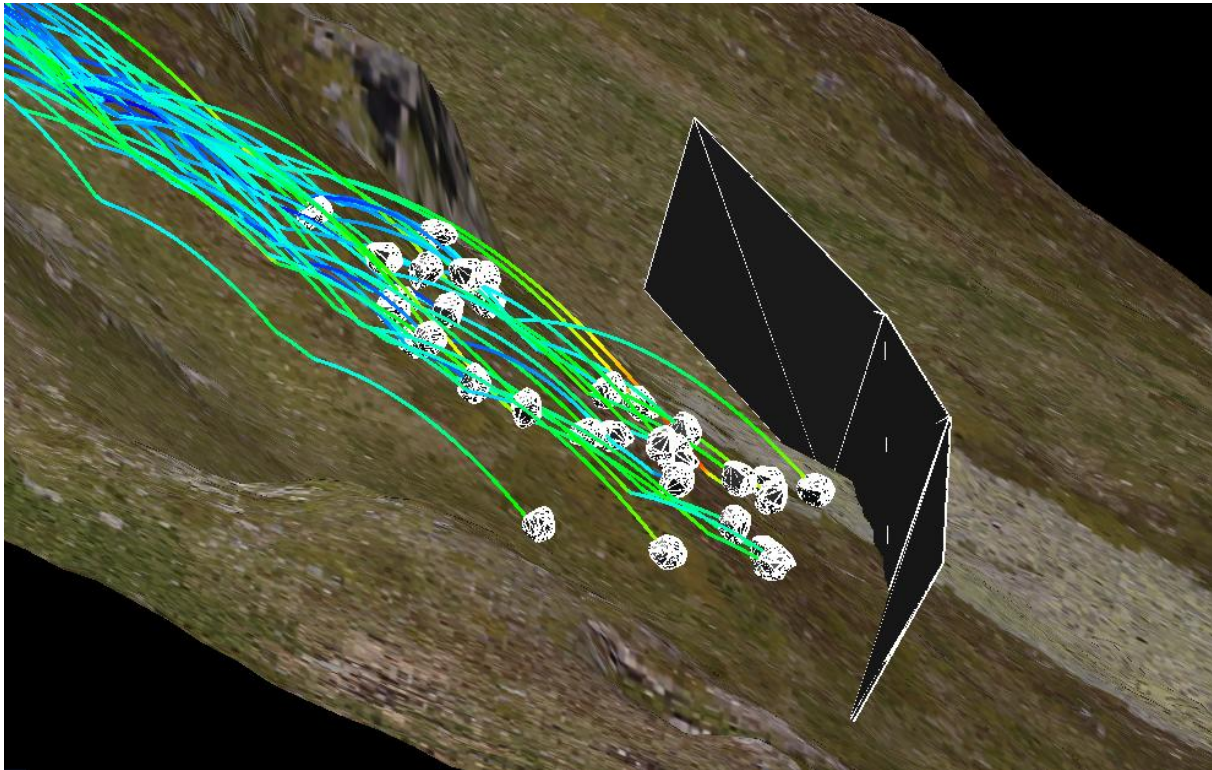


Figure 7-44: Rock impacts on obstacle (net)

The following parameters are stored for each first impact:

- **X-Coord (m)** – X coordinate of the impact point (**before impact**).
- **Y-Coord (m)** – Y coordinate of the impact point (**before impact**).
- **Z-Coord (m)** – Z elevation of the impact point (**before impact**).
- **Impact Angle (°)** – Angle between the incoming velocity vector and the local obstacle surface (0° = grazing along the surface, 90° = perpendicular impact.)
- **Kin. Energy pre (kJ)** – Kinetic energy of the rock **immediately before** the first impact.
- **Kin. Energy post (kJ)** – Kinetic energy of the rock **immediately after** the first impact.
- **Velocity_Res pre (m/s)** – Magnitude of the velocity vector **before** impact
- **Velocity_X pre (m/s)** – X component of the velocity **before** impact.
- **Velocity_Y pre (m/s)** – Y component of the velocity **before** impact.
- **Velocity_Z pre (m/s)** – Z component of the velocity **before** impact.
- **Velocity_Res post (m/s)** – Magnitude of the velocity vector **after** impact
- **Velocity_X post (m/s)** – X component of the velocity **after** impact.

- **Velocity_Y post (m/s)** – Y component of the velocity **after** impact.
- **Velocity_Z post (m/s)** – Z component of the velocity **after** impact.
- **Rock mass (kg)** – Mass of the rock.
- **Trajectory name**

Notes:

- **“pre”** always refers to the state immediately **before** the first contact with the obstacle.
- **“post”** refers to the state immediately **after** that first contact (after the numerical impact update).
- All coordinates (X, Y, Z) are taken at the **pre-impact** state.
- **“_Res”** denotes the **resultant velocity**, i.e. the length of the 3D velocity vector.

This CSV output makes it easy to post-process obstacle impacts in external tools (e.g. spreadsheets, Python, R) and to compare impact angles, energies, and velocities between different nets or dams.

ObstacleImpact_Shed410_DATA.csv

RAMMS | Obstacle Impact Data

Scenario: TestComparison_Stats 2.0_Full

Obstacle-File: C:\Users\MarcChristen\RAMMS_Beispieler\ROCKFALL\Testing_Update2.0\Parabolic\Shed410.pts

Date: 22/04/2025

Document was last saved: Just now

	X-Coord (m)	Y-Coord (m)	Z-Coord (m)	Impact Angle (°)	Kin. Energy pre (kJ)	Kin. Energy post (kJ)	Velocity_Res pre (m/s)	Velocity_Res post (m/s)	TestComparison_Stats							
1	2764141.10	1171433.10	411.16	47.76	676.61	274.75	20.75	-1.04	-13.43	-15.79	12.35	-2.84	-11.98	1.03	2706.76	TestComparison_Stats
2	2764268.29	1171433.68	411.19	44.24	834.23	567.28	22.32	1.80	-15.39	-16.06	17.43	5.20	-16.17	3.89	2706.76	TestComparison_Stats
3	2764267.58	1171435.28	411.23	47.53	815.37	462.96	22.49	2.25	-14.50	-17.05	15.69	2.16	-14.91	4.38	2706.76	TestComparison_Stats
4	2764243.43	1171435.69	411.24	50.31	795.41	353.30	22.38	2.19	-13.58	-17.66	14.02	-0.34	-14.01	-0.08	2706.76	TestComparison_Stats
5	2764181.41	1171431.78	411.14	47.72	815.88	414.92	22.03	3.04	-13.99	-16.74	14.96	1.10	-14.89	0.91	2706.76	TestComparison_Stats
6	2764212.41	1171436.05	411.26	34.46	764.93	93.02	22.17	-0.08	-12.55	-18.28	7.17	0.93	-6.62	2.59	2706.76	TestComparison_Stats
7	2764198.29	1171433.95	411.19	37.63	525.56	318.44	17.39	-0.07	-13.44	-11.05	13.20	-2.87	-12.87	0.65	2706.76	TestComparison_Stats
8	2764274.34	1171434.63	411.23	36.05	688.27	589.63	19.83	3.52	-15.27	-12.15	18.06	3.79	-17.22	-3.93	2706.76	TestComparison_Stats
9	2764275.96	1171432.84	411.15	48.12	779.77	471.20	22.37	0.59	-14.40	-17.11	15.91	1.79	-15.73	-1.54	2706.76	TestComparison_Stats
10	2764308.35	1171433.63	411.19	44.92	610.89	310.43	19.46	-1.47	-13.27	-14.17	13.06	-1.30	-12.98	0.62	2706.76	TestComparison_Stats
11	2764209.20	1171434.67	411.22	48.37	565.28	158.78	18.93	-1.55	-12.03	-14.53	8.95	-0.91	-8.63	2.19	2706.76	TestComparison_Stats
12	2764307.41	1171434.41	411.19	50.87	907.71	223.97	24.17	-2.05	-14.52	-19.21	11.16	4.20	-8.96	5.16	2706.76	TestComparison_Stats
13	2764241.32	1171435.67	411.25	48.07	528.34	195.78	18.57	2.26	-11.77	-14.19	10.27	6.74	-7.52	1.87	2706.76	TestComparison_Stats
14	2764162.98	1171434.94	411.23	39.57	431.81	285.55	16.08	1.00	-12.03	-10.62	12.70	-0.77	-12.65	-0.68	2706.76	TestComparison_Stats
15	2764241.34	1171436.05	411.25	33.98	609.20	609.20	18.37	3.07	-14.59	-10.73	18.37	3.07	-14.59	-10.73	2706.76	TestComparison_Stats
16	2764178.96	1171432.76	411.15	41.34	681.68	474.94	20.43	0.65	-14.90	-13.97	16.22	-0.80	-16.13	1.46	2706.76	TestComparison_Stats
17	2764238.32	1171435.86	411.24	52.82	904.09	72.46	23.97	1.16	-13.84	-19.54	5.68	5.52	-0.80	1.06	2706.76	TestComparison_Stats
18	2764175.19	1171436.01	411.26	46.20	411.30	296.95	16.09	-3.31	-11.62	-10.63	12.47	-3.97	-11.73	1.42	2706.76	TestComparison_Stats
19	2764214.21	1171435.75	411.26	49.66	472.88	242.40	16.58	0.83	-12.64	-10.70	11.52	-0.05	-11.32	2.10	2706.76	TestComparison_Stats
20	2764256.52	1171433.52	411.18	37.43	560.27	463.93	18.03	0.46	-13.96	-11.40	15.88	2.09	-15.36	-3.45	2706.76	TestComparison_Stats
21	2764256.19	1171435.47	411.25	45.14	769.29	430.80	21.76	1.08	-14.82	-15.89	15.47	2.41	-15.28	-0.27	2706.76	TestComparison_Stats
22	2764177.67	1171436.06	411.12	38.88	393.64	45.58	15.80	0.87	-9.92	-12.27	4.98	-1.75	-4.27	1.89	2706.76	TestComparison_Stats
23	2764320.64	1171435.56	411.24	43.33	457.05	236.20	16.62	1.79	-11.60	-11.77	11.40	0.45	-11.37	0.69	2706.76	TestComparison_Stats
24	2764198.25	1171432.11	411.14	39.05	665.97	349.21	20.05	-3.28	-14.82	-13.10	13.99	-4.62	-13.10	1.73	2706.76	TestComparison_Stats
25	2764231.61	1171432.54	411.16	41.92	596.87	487.56	18.87	0.50	-13.63	-13.04	16.10	0.48	-16.03	-1.48	2706.76	TestComparison_Stats

Figure 7-45: Output csv-file

7.5.3 Impact Analysis from Shapefile

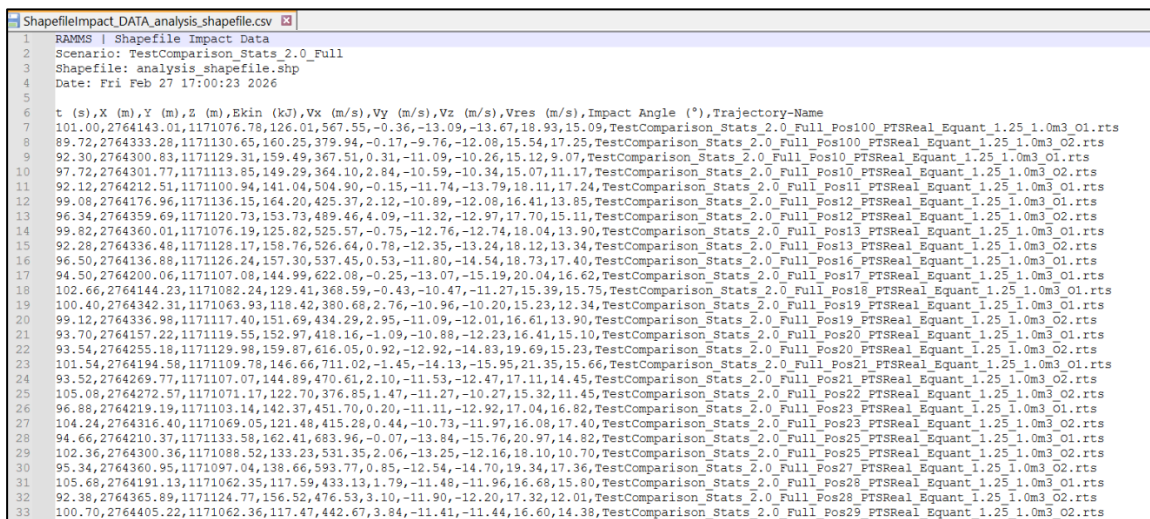
Menu: **Results → Impact Analysis from shapefile**

This feature can be used to analyze rock impacts within polygon areas on terrain (e.g. roads, dams). Do not use this feature for impacts on obstacles (see chapter *Impact Analysis: Barrier/Dam/Shed (from pts)* instead).

- Open a scenario in Statistics-Mode
- draw a polygon shapefile where you want to analyze trajectory impacts
- Choose **Results** → **Impact Analysis** from Shapefile and select above shapefile

RAMMS will then create a html-report of your shed impact analysis, with the most important results (statistical plots). Impact angles are explained in chapter 7.8. The following files are created:

- ShapefileImpact_PLOTS_<shapefile_name>.html: Statistical plots for kin. Energy (pre-impact), impact angle and velocity.
- ShapefileImpact_DATA_<shapefile_name>.csv: Complete data of impact analysis (impact time and location, kin. Energy, velocities, impact angle and trajectory name)



t (s)	X (m)	Y (m)	Z (m)	Ekin (kJ)	Vx (m/s)	Vy (m/s)	Vz (m/s)	Vres (m/s)	Impact Angle (°)	Trajectory-Name
101.00	2764143.01	1171076.78	126.01	567.55	-0.36	-13.09	-13.67	18.93	15.09	TestComparison_Stats_2.0_Full_Pos100_PTSReal_Equant_1.25_1.0m3_01.rts
89.72	2764333.28	1171130.65	160.25	379.94	-0.17	-9.76	-12.08	15.54	17.25	TestComparison_Stats_2.0_Full_Pos100_PTSReal_Equant_1.25_1.0m3_02.rts
92.30	2764300.83	1171129.31	159.49	367.51	0.31	-11.09	-10.26	15.12	9.07	TestComparison_Stats_2.0_Full_Pos10_PTSReal_Equant_1.25_1.0m3_01.rts
97.72	2764301.77	1171113.85	149.29	364.10	2.84	-10.59	-10.34	15.07	11.17	TestComparison_Stats_2.0_Full_Pos10_PTSReal_Equant_1.25_1.0m3_02.rts
92.12	2764212.51	1171100.94	141.04	504.90	-0.15	-11.74	-13.79	18.11	17.24	TestComparison_Stats_2.0_Full_Pos11_PTSReal_Equant_1.25_1.0m3_01.rts
99.08	2764176.96	1171136.15	164.20	425.37	2.12	-10.89	-12.08	16.41	13.85	TestComparison_Stats_2.0_Full_Pos12_PTSReal_Equant_1.25_1.0m3_01.rts
96.34	2764359.69	1171120.73	153.73	489.46	4.09	-11.32	-12.97	17.70	15.11	TestComparison_Stats_2.0_Full_Pos12_PTSReal_Equant_1.25_1.0m3_02.rts
99.82	2764360.01	1171076.19	125.82	525.57	-0.75	-12.76	-12.74	18.04	13.90	TestComparison_Stats_2.0_Full_Pos13_PTSReal_Equant_1.25_1.0m3_01.rts
92.28	2764336.48	1171128.17	158.76	526.64	0.78	-12.35	-13.24	18.12	13.34	TestComparison_Stats_2.0_Full_Pos13_PTSReal_Equant_1.25_1.0m3_02.rts
96.50	2764136.88	1171126.24	157.30	537.45	0.53	-11.80	-14.54	18.73	17.40	TestComparison_Stats_2.0_Full_Pos16_PTSReal_Equant_1.25_1.0m3_01.rts
94.50	2764200.06	1171107.08	144.99	622.08	-0.25	-13.07	-15.19	20.04	16.62	TestComparison_Stats_2.0_Full_Pos17_PTSReal_Equant_1.25_1.0m3_01.rts
102.66	2764144.23	1171082.24	129.41	368.59	-0.43	-10.47	-11.27	15.39	15.75	TestComparison_Stats_2.0_Full_Pos18_PTSReal_Equant_1.25_1.0m3_01.rts
100.40	2764342.31	1171063.93	118.42	380.68	2.76	-10.96	-10.20	15.23	12.34	TestComparison_Stats_2.0_Full_Pos19_PTSReal_Equant_1.25_1.0m3_01.rts
99.12	2764336.98	1171117.40	151.69	434.29	2.95	-11.09	-12.01	16.61	13.90	TestComparison_Stats_2.0_Full_Pos19_PTSReal_Equant_1.25_1.0m3_02.rts
93.70	2764157.22	1171119.55	152.97	418.16	-1.09	-10.88	-12.23	16.41	15.10	TestComparison_Stats_2.0_Full_Pos20_PTSReal_Equant_1.25_1.0m3_01.rts
93.54	2764255.18	1171129.98	159.97	616.05	0.92	-12.92	-14.83	19.69	15.23	TestComparison_Stats_2.0_Full_Pos20_PTSReal_Equant_1.25_1.0m3_02.rts
101.54	2764194.58	1171109.78	146.66	711.02	-1.45	-14.13	-15.95	21.35	15.66	TestComparison_Stats_2.0_Full_Pos21_PTSReal_Equant_1.25_1.0m3_01.rts
93.52	2764269.77	1171107.07	144.89	470.61	2.10	-11.53	-12.47	17.11	14.45	TestComparison_Stats_2.0_Full_Pos21_PTSReal_Equant_1.25_1.0m3_02.rts
105.08	2764272.57	1171071.17	122.70	376.85	1.47	-11.27	-10.27	15.32	11.45	TestComparison_Stats_2.0_Full_Pos22_PTSReal_Equant_1.25_1.0m3_02.rts
96.88	2764219.19	1171103.14	142.37	451.70	0.20	-11.11	-12.92	17.04	16.82	TestComparison_Stats_2.0_Full_Pos23_PTSReal_Equant_1.25_1.0m3_01.rts
104.24	2764316.40	1171069.05	121.48	415.28	0.44	-10.73	-11.97	16.08	17.40	TestComparison_Stats_2.0_Full_Pos23_PTSReal_Equant_1.25_1.0m3_02.rts
94.66	2764210.37	1171133.58	162.41	683.96	-0.07	-13.84	-15.76	20.97	14.82	TestComparison_Stats_2.0_Full_Pos25_PTSReal_Equant_1.25_1.0m3_01.rts
102.36	2764300.36	1171088.52	133.23	531.35	2.06	-13.25	-12.16	18.10	10.70	TestComparison_Stats_2.0_Full_Pos25_PTSReal_Equant_1.25_1.0m3_02.rts
95.34	2764360.95	1171097.04	138.66	593.77	0.85	-12.54	-14.70	19.34	17.36	TestComparison_Stats_2.0_Full_Pos27_PTSReal_Equant_1.25_1.0m3_02.rts
105.68	2764191.13	1171062.35	117.59	433.13	1.79	-11.48	-11.96	16.68	15.80	TestComparison_Stats_2.0_Full_Pos28_PTSReal_Equant_1.25_1.0m3_01.rts
92.38	2764365.89	1171124.77	156.52	476.53	3.10	-11.90	-12.20	17.32	12.01	TestComparison_Stats_2.0_Full_Pos28_PTSReal_Equant_1.25_1.0m3_02.rts
100.70	2764405.22	1171062.36	117.47	442.67	3.84	-11.41	-11.44	16.60	14.38	TestComparison_Stats_2.0_Full_Pos29_PTSReal_Equant_1.25_1.0m3_02.rts

Figure 7-46: ShapefileImpact_DATA_<shapefile_name>.csv containing impact-analysis data.

7.5.4 ASTRA-Analysis from Shapefile (Terrain)

Menu: **Results** → **ASTRA-Analysis from Shapefile (Terrain)**

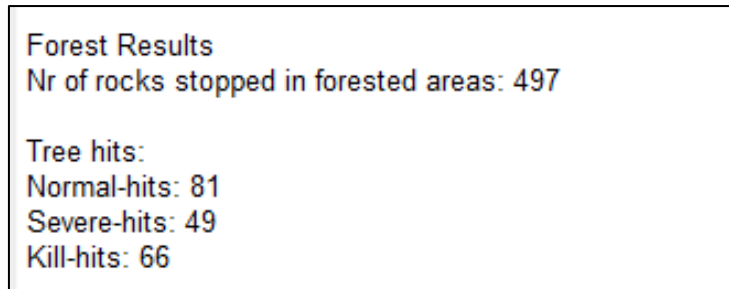
Choose a shapefile to do an ASTRA-Analysis (same analysis as in section 7.5.1) for rocks on terrain.

7.6 Forest Information

When forests are enabled in a scenario, RAMMS provides results in three complementary ways: **logfile summaries**, **on-map visualization**, and **collision datasets**.

7.6.1 Logfile summary

In the scenario logfile you'll find a compact forest overview (see *Figure below*), including counts for:



```
Forest Results
Nr of rocks stopped in forested areas: 497

Tree hits:
Normal-hits: 81
Severe-hits: 49
Kill-hits: 66
```

Figure 7-47: Forest information in the scenario logfile.

- **Normal hits** – Tree is hit but not destroyed; rock is deflected.
- **Severe hits** – Tree is partially destroyed; rock is deflected.
- **Kill hits** – Tree is destroyed; the rock no longer “sees” this tree

These categories are derived from the tree energy threshold and the rock's kinetic energy at impact.

7.6.2 Visualizing trees

Choose **Show → Trees** to display impacted trees (see *Figure below*).

Color coding:

- **Green** = No hit
- **Yellow** = Normal hit
- **Orange** = Severe hit
- **Red** = Kill hit

Only trees **near the simulated trajectories** are shown to keep maps clean on large forest areas (note: distant forest stands are intentionally hidden, see red arrow in the *Figure below*).

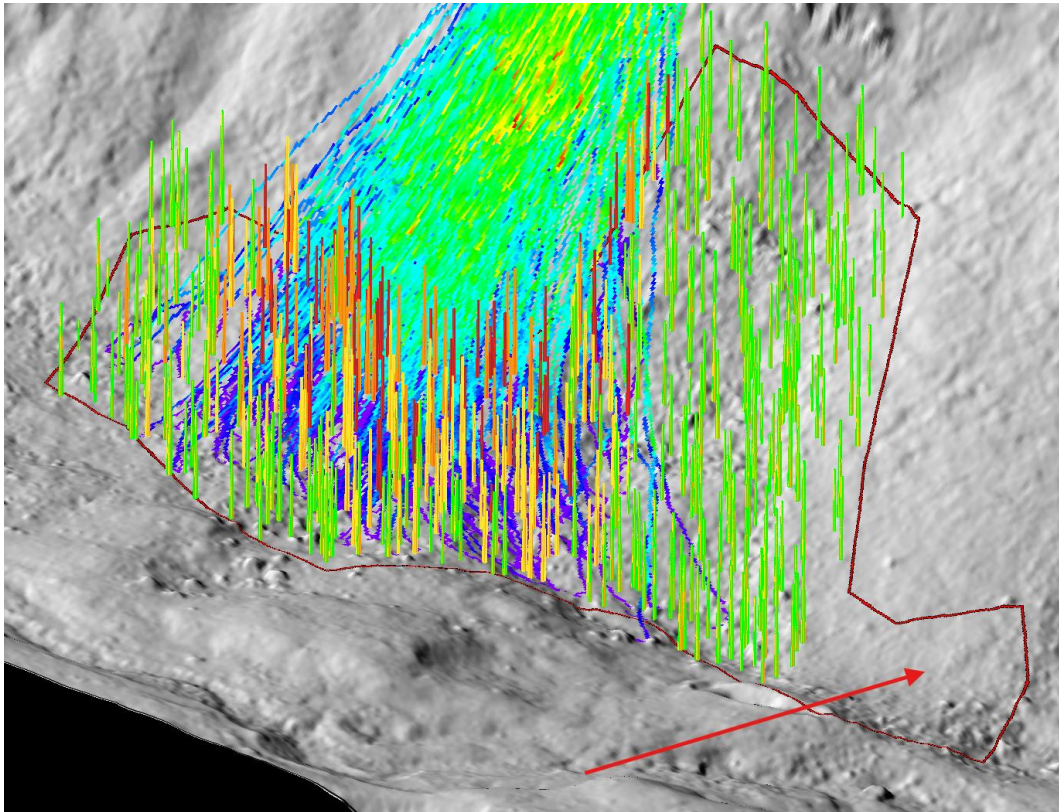


Figure 7-48: Tree visualization

7.6.3 Tree collision data

On first open of a scenario, RAMMS scans the tree-collision logs and creates shapefiles for analysis and GIS use:

- <scenario_name>_treecollisions.shp:
Point layer with one feature per recorded tree impact. Key attributes:
 - **TreeIndex** – internal tree ID
 - **Time (s)** – impact time
 - **Height (m)** – average collision height on trunk
 - **Ecc** – eccentricity of impact
 - **RockMass** (kg)
 - **RockEnergy** (kJ) – kinetic energy at impact
 - **TreeDiam** (m) – tree diameter used for the collision model
 - **TreeThresh** (kJ) – tree energy threshold
 - **Factor** (–) – threshold factor applied (energy multiplier)
 - **Invisible** (0/1) – 1 if the tree is considered invisible to the rock after a kill hit

- <scenario_name>_destroyed_trees.shp:
Point layer listing destroyed trees (kill hits) by TreeIndex.

Data sources & performance notes

- RAMMS reads collision logs generated during simulation.
 - Legacy per-trajectory files: .tes
 - Consolidated per-worker containers: .tec
- On first read, data are parsed and cached; subsequent opens reuse the cache for faster loading.

7.7 Exporting Video, Image or GIF animation

7.7.1 Video (mp4)

It is possible to use **FFmpeg** to export videos from rockfall simulations in *Trajectory*-mode. FFmpeg is a leading Open-Source multimedia framework. FFmpeg is not bundled with RAMMS due to licensing constraints. You therefore have to download the ffmpeg-binary yourself, by following this procedure once:

1. Download FFmpeg: Visit the official FFmpeg builds page -> <https://www.gyan.dev/ffmpeg/builds/>
2. Choose the correct version: Download the archive named "ffmpeg-release-essentials.7z" or "ffmpeg-release-essentials.zip"
3. Extract and locate *ffmpeg.exe*: After extraction, find *ffmpeg.exe* inside the bin folder.
4. Copy *ffmpeg.exe* to the "bin" folder of your RAMMS installation (You may need administrator privileges to copy files into this location).
5. If you do not have administrator privileges, then copy *ffmpeg.exe* to any location on your computer, and then add the full path to the *ffmpeg.exe* file in the GUI Preferences like this:

FFMPEG <full_path_to_ffmpeg.exe_file> (without <>)
(if the path contains blancs, you need " ")

Once added, RAMMS will automatically detect it and enable video export functionality.

7.7.2 Image

It is possible to export your results as an image in different formats (e.g. .png, .jpg, .gif, .tif etc.). Click  or choose **Track** → **Export...** → **Image File** and define a file name with the corresponding extension. An image of the visible part in the viewer will then be exported to your scenario-directory.

7.7.3 GIF animation

Creating a GIF animation is only possible in output mode. Click  or choose **Track** → **Export...** → **GIF Animation**. Enter a file name and location and wait until the simulation stopped. As soon as the simulation finished, the GIF animation file is saved. In the *Preferences* you can define the interval for the GIF animation (GIF animation interval (s)) in the *Rockfall* tab.

7.8 Impact Angles

In earlier RAMMS::Rockfall versions the impact angle was computed under the **implicit assumption of a horizontal terrain**.

If the total velocity vector at impact is

$$\mathbf{v} = (v_x, v_y, v_z)$$

the “old” impact angle α was defined as the angle between the trajectory and the **horizontal plane**:

$$\alpha_{\text{old}} = \arcsin\left(\frac{|v_z|}{\|\mathbf{v}\|}\right)$$

This is equivalent to looking only at the vertical component v_z . It works correctly only for **flat terrain** and does *not* reflect the true impact geometry on steep slopes or on inclined structures such as rockfall nets or dams.

General formulation using surface normals

We now define the impact angle with respect to the **local surface plane** at the impact point, independent of whether it is:

- the terrain (DEM cell), or
- a facet of an obstacle (pts-object, e.g. a rockfall net or dam).

At each impact we know:

- the **impact velocity** $\mathbf{v}$
- the unit **normal vector of the local surface**, $\hat{\mathbf{n}}$

The normal vector $\hat{n}$ is oriented **outwards** from the surface:

- For the DEM: out of the terrain.
- For obstacles: out of the convex hull of the pts-object.

We define the impact angle α as:

The angle between the trajectory and the surface **plane**, where 0° = grazing along the surface and 90° = perpendicular impact.

7.9 FULL vs. REDUCED output mode

RAMMS::Rockfall can export results in two packaging styles:

- **Full mode (per trajectory)**: one file per trajectory — .rts for trajectories, .bes for obstacle hits, .tes for tree hits.
- **Container mode (per process/CPU)**: many trajectories batched into one file per worker — .rtc for trajectories, .bec for obstacle hits, .tec for tree hits.

Both modes are supported by post-processing. The **big difference** is **how much data** each trajectory carries.

In container mode we deliberately store **only**:

Kinetic energy, Jump height, Velocity (resultant), Scar depth, plus **X/Y** (we get zt from the DEM to reconstruct Z). Everything else from the full dump is **not written** to reduce size and accelerate I/O.

Obstacle / tree impact logs

- **Full**: .bes (barriers) and .tes (trees) written per trajectory.
- **Container**: .bec and .tec written per process.
- The recorded impact attributes are equivalent for analysis; container files just batch many impacts.

Why use container mode?

- **Far fewer files** (faster OS operations, backups, virus scans).
- **Much faster writes** (large sequential I/O).
- **Smaller total size** because we keep only the variables most analyses use.

When full mode is preferable

- You need **velocity components, rotation**, or other detailed per-step fields for your own custom diagnostics.
- You want each trajectory self-contained for ad-hoc sharing or inspection

Implications for analysis

- All standard RAMMS statistics (e.g., **reach probability**, per-cell **median/quantiles of Jump height / Velocity / Kinetic energy / Scar depth**) are available in both modes.
- Analyses that require **rotation** or **velocity components** (vx, vy, vz) are only possible in FULL mode (full.rts).
 - In container workflows those signals are **not present**; RAMMS will not fabricate them. (We may still reconstruct **Z** as $z_t + \text{JumpHeight}$.)
- Your SOL-line workflow (pEr, prA) and **Jump height** vs **Kinetic energy** plots at first crossing) work **unchanged** in both modes.

8 References and further reading

8.1 References

Maps and aerial images

- ➔ All topographic base maps and aerial images from Source: Swiss Federal Office of Topography

Manual Literature

- Acary, V. and Brogliato, B., 2008: Numerical Methods for non-smooth Dynamical Systems; Applications in Mechanics and Electronics. In: Dynamics of Non-Smooth Systems. Lecture Notes in Applied and Computational Mechanics, 35, Springer, Berlin.
- Bourrier, F., Dorren, L., Nicot, F., Berger, F., and Darve, F., (2009): Toward objective rockfall trajectory simulation using a stochastic impact model. *Geomorphology*, 110(3-4): 68-79.
- Bourrier, F., Berger, F., Tardif, P., Dorren, L., and Hungr, O., 2012: Rockfall rebound: comparison of detailed field experiments and alternative modeling approaches. *Earth Surface Processes and Landforms*, 37(6): 656-665.
- Cross, R., (1999): The bounce of a ball. *American Journal of Physics*, 67(3):222–227. [8] Fityus, S., Giacomini, A., and Buzzi, O., (2013): The significance of geology for the morphology of potentially unstable rocks. *Engineering Geology*, 162(0): 43-52.
- Dorren, L., 2003: A review of rockfall mechanics and modeling approaches. *Progress in Physical Geography*, 27(1):6987.
- Dorren, L. and Berger F. 2006: Stem breakage of trees and energy dissipation during rockfall impacts. *Tree Physiology*, Volume 26, Issue 1, January 2006, Pages 63–71, <https://doi.org/10.1093/treephys/26.1.63>.
- Dorren, L. K. A. and Seijmonsbergen, A. C. 2003: Comparison of three GIS-based models for predicting rockfall runout zones at a regional scale. *Geomorphology*, 56(1-2):49 - 64.
- Fityus, S., Giacomini, A., and Buzzi, O. 2013: The significance of geology for the morphology of potentially unstable rocks. *Engineering Geology*, 162:43 - 52.
- Frehner, M., Wasser, B., Schwitter, R. 2005: Nachhaltigkeit und Erfolgskontrolle im Schutzwald. Wegleitung für Pflegemassnahmen in Wäldern mit Schutzfunktion. Bern: Bundesamt für Umwelt. 564p.

- Glocker, Ch., 2001: Set-Valued Forces Laws. In: Dynamics of Non-Smooth Systems. Lecture Notes in Applied and Computational Mechanics, 1, Springer, Berlin.
- Glover, J., (2015): Rock-shape and its role in rockfall dynamics. Doctoral thesis, Durham University.
- Latham, J.-P.; Munjiza, A.; Garcia, X.; Xiang, J. and Guises, R., 2008: Three-dimensional particle shape acquisition and use of shape library for DEM and FEM/DEM simulation. In: Minerals Engineerings, Elsevier, 797-805.
- Leine, R. I.; Schweizer, A.; Christen, M.; Glover, J.; Bartelt, P. and Gerber, W., 2014: Simulation of rockfall trajectories with consideration of rock shape. Multibody System Dynamics 32, 2: 241 - 271.
- Moreau, J.J., 1988: Unilateral contact and dry friction in finite freedom dynamics. In: Non-Smooth Mechanics and Applications, Springer, Berlin, 1-82.
- Jaboyedoff, M., (2011): Slope tectonics. Geological Society London.
- Schweizer, A. 2015: Ein nichtglattes mechanisches Modell für Steinschlag. Dissertation ETH Zürich Nr. 22559.
- Volkwein, A., Schellenberg, K., Labiouse, V., Agliardi, F., Berger, F., Bourrier, F., Dorren, L. K. A., Gerber, W., and Jaboyedoff, M. 2011: Rockfall characterization and structural protection - a review. Natural Hazards and Earth System Science, 11(9):2617 - 2651.

8.2 Publications

The development of RAMMS::Rockfall is based on scientific findings published in international scientific journals. A list of the most important scientific publications about RAMMS::Rockfall and its applications is given below (chronological order). This publication-list is also available on our webpage:
<https://www.ramms.ch/ramms-rockfall/>

Key ROCKFALL Publications

- Leine, R.I.; Capobianco, G.; Bartelt, P.; Christen, M.; Caviezel, A., 2021: Stability of rigid body motion through an extended intermediate axis theorem: application to rockfall simulation. Multibody System Dynamics, 52: 431-455. doi: 10.1007/s11044-021-09792-y
- Caviezel, A.; Ringenbach, A.; Demmel, S.E.; Dinneen, C.E.; Krebs, N.; Bühler, Y.; Christen, M.; Meyrat, G.; Stoffel, A.; Hafner, E.; Eberhard, L.A.; Von Rickenbach, D.; Simmler, K.; Mayer, P.; Niklaus, P.S.; Birchler, T.; Aebi, T.; Cavigelli, L.; Schaffner, M.; ... Bartelt, P., 2021: The relevance of rock shape over mass -

implications for rockfall hazard assessments. *Nature Communications*, 12: 5546 (9 pp.). doi: 10.1038/s41467-021-25794-y

Lu, G.; Ringenbach, A.; Caviezel, A.; Sanchez, M.; Christen, M.; Bartelt, P., 2021: Mitigation effects of trees on rockfall hazards: does rock shape matter?. *Landslides*, 18: 59-77. doi: 10.1007/s10346-020-01418-2

Lu, G.; Caviezel, A.; Christen, M.; Demmel, S.E.; Ringenbach, A.; Bühler, Y.; Dinneen, C.E.; Gerber, W.; Bartelt, P., 2019: Modelling rockfall impact with scarring in compactable soils. *Landslides*, 16: 2353-2367. doi: 10.1007/s10346-019-01238-z

Caviezel, A.; Demmel, S.E.; Ringenbach, A.; Bühler, Y.; Lu, G.; Christen, M.; Dinneen, C.E.; Eberhard, L.A.; Von Rickenbach, D.; Bartelt, P., 2019: Reconstruction of four-dimensional rockfall trajectories using remote sensing and rock-based accelerometers and gyroscopes. *Earth Surface Dynamics*, 7, 1: 199-210. doi: 10.5194/esurf-7-199-2019

Caviezel, A.; Schaffner, M.; Cavigelli, L.; Niklaus, P.; Bühler, Y.; Bartelt, P.; Magno, M.; Benini, L., 2018: Design and evaluation of a low-power sensor device for induced rockfall experiments. *IEEE Transactions on Instrumentation and Measurement*, 67, 4: 767-779. doi: 10.1109/TIM.2017.2770799

Leine, R.I.; Schweizer, A.; Christen, M.; Glover, J.; Bartelt, P.; Gerber, W., 2014: Simulation of rockfall trajectories with consideration of rock shape. *Multibody System Dynamics*, 32, 2: 241-271. doi: 10.1007/s11044-013-9393-4

ROCKFALL Publication List

Leine, R.I.; Capobianco, G.; Bartelt, P.; Christen, M.; Caviezel, A., 2021: Stability of rigid body motion through an extended intermediate axis theorem: application to rockfall simulation. *Multibody System Dynamics*, 52: 431-455. doi: 10.1007/s11044-021-09792-y

Caviezel, A.; Ringenbach, A.; Demmel, S.E.; Dinneen, C.E.; Krebs, N.; Bühler, Y.; Christen, M.; Meyrat, G.; Stoffel, A.; Hafner, E.; Eberhard, L.A.; Von Rickenbach, D.; Simmler, K.; Mayer, P.; Niklaus, P.S.; Birchler, T.; Aebi, T.; Cavigelli, L.; Schaffner, M.; ... Bartelt, P., 2021: The relevance of rock shape over mass - implications for rockfall hazard assessments. *Nature Communications*, 12: 5546 (9 pp.). doi: 10.1038/s41467-021-25794-y

Lu, G.; Ringenbach, A.; Caviezel, A.; Sanchez, M.; Christen, M.; Bartelt, P., 2021: Mitigation effects of trees on rockfall hazards: does rock shape matter?. *Landslides*, 18: 59-77. doi: 10.1007/s10346-020-01418-2

- Sanchez, M.A.; Caviezel, A., 2020: Full-scale testing of rockfall nets in real terrain. Results of tests at Chant Sura: 13th September and 4th October, 2019. WSL Berichte, 97. 81 p.
- Ringenbach, A.; Caviezel, A.; Demmel, S.E.; Lu, G.; Bühler, Y.; Christen, M.; Bartelt, P.; Meier, L., 2020: Three-dimensional trajectory reconstruction of induced single block rockfall experiments. In: Da Fontoura, S.A.B.; Rocca, R.J.; Pavón Mendoza, J.F. (eds), 2020: Rock Mechanics for Natural Resources and Infrastructure Development - Full Papers. Proceedings. 14th international congress on rock mechanics and rock engineering (ISRM 2019), Foz do Iguassu, Brazil. 2887-2894.
- Wendeler, C.; Lanter, A.; Lu, G.; Caviezel, A.; Ringenbach, A.; Bartelt, P., 2020: New rockfall testing method of flexible rockfall barriers. In: Da Fontoura, S.A.B.; Rocca, R.J.; Pavón Mendoza, J.F. (eds), 2020: Rock Mechanics for Natural Resources and Infrastructure Development - Full Papers. Proceedings. 14th international congress on rock mechanics and rock engineering (ISRM 2019), Foz do Iguassu, Brazil. 3416-3423.
- Caviezel, A.; Lu, G.; Demmel, S.E.; Ringenbach, A.; Bühler, Y.; Christen, M.; Bartelt, P., 2019: RAMMS::ROCKFALL - a modern 3-dimensional simulation tool calibrated on real world data. In: 2019: 53rd US rock mechanics/geomechanics symposium. 53rd US rock mechanics/geomechanics symposium, New York, USA. ARMA 19-223 (8 pp.).
- Caviezel, A.; Demmel, S.E.; Ringenbach, A.; Bühler, Y.; Lu, G.; Christen, M.; Dinneen, C.E.; Eberhard, L.A.; Von Rickenbach, D.; Bartelt, P., 2019: Reconstruction of four-dimensional rockfall trajectories using remote sensing and rock-based accelerometers and gyroscopes. *Earth Surface Dynamics*, 7, 1: 199-210. doi: 10.5194/esurf-7-199-2019
- Lu, G.; Caviezel, A.; Christen, M.; Demmel, S.E.; Ringenbach, A.; Bühler, Y.; Dinneen, C.E.; Gerber, W.; Bartelt, P., 2019: Modelling rockfall impact with scarring in compactable soils. *Landslides*, 16: 2353-2367. doi: 10.1007/s10346-019-01238-z
- Caviezel, A.; Gerber, W., 2018: Brief communication: measuring rock decelerations and rotation changes during short-duration ground impacts. *Natural Hazards and Earth System Science*, 18, 11: 3145-3151. doi: 10.5194/nhess-18-3145-2018
- Lu, G.; Caviezel, A.; Christen, M.; Ringenbach, A.; Meyrat, G.; Bartelt, P., 2019: Non-smooth mechanics modelling of rock-tree and rock-forest interactions. In: Papadrakakis, M.; Fragiadakis, M. (eds), 2019: COMPDYN 2019. 7th international conference on computational methods in structural dynamics and earthquake engineering. Proceedings. COMPDYN 2019. 7th ECCOMAS thematic conference

- on computational methods in structural dynamics and earthquake engineering, Crete, Greece. 1612-1629.
- Caviezel, A.; Schaffner, M.; Cavigelli, L.; Niklaus, P.; Bühler, Y.; Bartelt, P.; Magno, M.; Benini, L., 2018: Design and evaluation of a low-power sensor device for induced rockfall experiments. *IEEE Transactions on Instrumentation and Measurement*, 67, 4: 767-779. doi: 10.1109/TIM.2017.2770799
- Gerber, W.; Caviezel, A., 2018: Measurement and analysis of ground contacts during rockfall events. In: Cardoso, A.S.; Borges, J.L.; Costa, P.A.; Gomes, A.T.; Marques, J.C.; Vieira, C.S. (eds), 2018: Numerical methods in geotechnical engineering IX. 9th European conference on numerical methods in geotechnical engineering (NUMGE 2018), Porto. 149-154.
- Caviezel, A.; Bühler, Y.; Lu, G.; Christen, M.; Bartelt, P., 2018: Experimental validation of numerical rockfall trajectory models. In: Cardoso, A.S.; Borges, J.L.; Costa, P.A.; Gomes, A.T.; Marques, J.C.; Vieira, C.S. (eds), 2018: Numerical methods in geotechnical engineering IX. 9th European conference on numerical methods in geotechnical engineering (NUMGE 2018), Porto. 875-883.
- Eichenberger, V.; McArdeell, B.; Christen, M.; Trappmann, D.; Stoffel, M., 2017: Wenn Baumwunden dazu beitragen, Steinschlagmodelle weiterzuentwickeln. *Schweizerische Zeitschrift für Forstwesen*, 168, 2: 84-91. doi: 10.3188/szf.2017.0084
- Niklaus, P.; Birchler, T.; Aebi, T.; Schaffner, M.; Cavigelli, L.; Caviezel, A.; Magno, M.; Benini, L., 2017: StoneNode: a low-power sensor device for induced rockfall experiments. In: 2017: 2017 IEEE sensors applications symposium (SAS). 2017 IEEE sensors applications symposium (SAS), Glassboro, NJ, USA. 16807856 (6 pp.). doi: 10.1109/SAS.2017.7894081
- Gerber, W.; Caviezel, A., 2017: Diversity of the results from drop weight tests. In: Corominas, J.; Moya, J.; Janeras, M. (eds), 2017: RocExs 2017. 6th interdisciplinary workshop on rockfall protection. 6th interdisciplinary workshop on rockfall protection (RocExs 2017), Barcelona, Catalonia, Spain. 63-66.
- Caviezel, A.; Christen, M.; Bühler, Y.; Bartelt, P., 2017: Calibration methods for numerical rockfall models based on experimental data. In: Corominas, J.; Moya, J.; Janeras, M. (eds), 2017: RocExs 2017. 6th interdisciplinary workshop on rockfall protection. 6th interdisciplinary workshop on rockfall protection (RocExs 2017), Barcelona, Catalonia, Spain. 59-62.
- Leine, R.I.; Schweizer, A.; Christen, M.; Glover, J.; Bartelt, P.; Gerber, W., 2014: Simulation of rockfall trajectories with consideration of rock shape. *Multibody System Dynamics*, 32, 2: 241-271. doi: 10.1007/s11044-013-9393-4

Glover, J.; Denk, M.; Bourrier, F.; Volkwein, A.; Gerber, W., 2012: Measuring the kinetic energy dissipation effects of rock fall attenuating systems with video analysis. In: Koboltschnig, G.; Hübl, J.; Braun, J. (eds), 2012: 12th congress INTERPRAEVENT 2012. 23 to 26 April 2012. Grenoble, France. Conference proceedings "Protection of living space from natural hazards". 12th congress INTERPRAEVENT 2012, Grenoble, France, April 23-26, 2012. 151-160.

9 Third-Party Software

The following third-party software components are used in RAMMS::Rockfall:

7-zip:

- RAMMS uses the 7-Zip command-line tool (7za.exe) developed by Igor Pavlov. Licensed under the GNU LGPL v2.1.
- The source code of 7-zip is available at www.7-zip.org.

Bullet v2.85

Bullet Continuous Collision Detection and Physics Library

<http://bulletphysics.org>

zlib-License (<http://opensource.org/licenses/Zlib>):

This software is provided 'as-is', without any express or implied warranty.

In no event will the authors be held liable for any damages arising from the use of this software. Permission is granted to anyone to use this software for any purpose, including commercial applications, and to alter it and redistribute it freely, subject to the following restrictions:

1. The origin of this software must not be misrepresented; you must not claim that you wrote the original software. If you use this software in a product, an acknowledgment in the product documentation would be appreciated but is not required.
2. Altered source versions must be plainly marked as such, and must not be misrepresented as being the original software.
3. This notice may not be removed or altered from any source distribution.

Boost Software License - Version 1.0 - August 17th, 2003

Permission is hereby granted, free of charge, to any person or organization obtaining a copy of the software and accompanying documentation covered by this license (the "Software") to use, reproduce, display, distribute, execute, and transmit the Software, and to prepare derivative works of the Software, and to permit third-parties to whom the Software is furnished to do so, all subject to the following:

The copyright notices in the Software and this entire statement, including the above license grant, this restriction and the following disclaimer, must be included in all copies of the Software, in whole or in part, and all derivative works of the Software, unless such copies or derivative works are solely in the form of machine-executable object code generated by a source language processor.

THE SOFTWARE IS PROVIDED "AS IS", WITHOUT WARRANTY OF ANY KIND, EXPRESS OR IMPLIED, INCLUDING BUT NOT LIMITED TO THE WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, TITLE AND NON-INFRINGEMENT. IN NO EVENT SHALL THE COPYRIGHT HOLDERS OR ANYONE DISTRIBUTING THE SOFTWARE BE LIABLE

FOR ANY DAMAGES OR OTHER LIABILITY, WHETHER IN CONTRACT, TORT OR OTHERWISE, ARISING FROM, OUT OF OR IN CONNECTION WITH THE SOFTWARE OR THE USE OR OTHER DEALINGS IN THE SOFTWARE.

QHull License:

Qhull, Copyright (c) 1993-2012

C.B. Barber
Arlington, MA

and

The National Science and Technology Research Center for
Computation and Visualization of Geometric Structures
(The Geometry Center)
University of Minnesota

email: qhull@qhull.org

This software includes Qhull from C.B. Barber and The Geometry Center. Qhull is copyrighted as noted above. Qhull is free software and may be obtained via [http](http://www.qhull.org) from www.qhull.org. It may be freely copied, modified, and redistributed under the following conditions:

1. All copyright notices must remain intact in all files.

2. A copy of this text file must be distributed along with any copies of Qhull that you redistribute; this includes copies that you have modified, or copies of programs or other software products that include Qhull.
3. If you modify Qhull, you must include a notice giving the name of the person performing the modification, the date of modification, and the reason for such modification.
4. When distributing modified versions of Qhull, or other software products that include Qhull, you must provide notice that the original source code may be obtained as noted above.
5. There is no warranty or other guarantee of fitness for Qhull, it is provided solely "as is". Bug reports or fixes may be sent to qhull_bug@qhull.org; the authors may or may not act on them as they desire.

Vollnt

```

/*****
*
*          *
*  vollnt.c          *
*          *
*  This code computes volume integrals needed for      *
*  determining mass properties of polyhedral bodies.  *
*          *
*  For more information, see the accompanying README  *
*  file, and the paper          *
*          *
*  Brian Mirtich, "Fast and Accurate Computation of   *
*  Polyhedral Mass Properties," journal of graphics  *
*  tools, volume 1, number 1, 1996.          *
*          *
*  This source code is public domain, and may be used *
*  in any way, shape or form, free of charge.          *
*          *
*  Copyright 1995 by Brian Mirtich          *
*          *
*  mirtich@cs.berkeley.edu          *
*  http://www.cs.berkeley.edu/~mirtich          *
*          *
*****/

```

Fanning Software Consulting:

- Some utility routines by Fanning Software Consulting (Scale_Vector() or FPUFIX() among others) are used in RAMMS.

```

,*****.
;
; Copyright (c) 1998-2013, by Fanning Software Consulting, Inc. All rights reserved. ;
; Redistribution and use in source and binary forms, with or without ;
; modification, are permitted provided that the following conditions are met:
;
; * Redistributions of source code must retain the above copyright ;
; notice, this list of conditions and the following disclaimer. ;
; * Redistributions in binary form must reproduce the above copyright ;
; notice, this list of conditions and the following disclaimer in the ;
; documentation and/or other materials provided with the distribution. ;
; * Neither the name of Fanning Software Consulting, Inc. nor the names of its ;
; contributors may be used to endorse or promote products derived from this ;
; software without specific prior written permission.
;
; THIS SOFTWARE IS PROVIDED BY FANNING SOFTWARE CONSULTING, INC. "AS IS"
AND ANY ;
; EXPRESS OR IMPLIED WARRANTIES, INCLUDING, BUT NOT LIMITED TO, THE IMPLIED
WARRANTIES ; OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE
ARE DISCLAIMED. IN NO EVENT ; SHALL FANNING SOFTWARE CONSULTING, INC.
BE LIABLE FOR ANY DIRECT, INDIRECT, ;
; INCIDENTAL, SPECIAL, EXEMPLARY, OR CONSEQUENTIAL DAMAGES (INCLUDING,
BUT NOT LIMITED ;
; TO, PROCUREMENT OF SUBSTITUTE GOODS OR SERVICES; LOSS OF USE, DATA, OR
PROFITS; ;
; LOSS OF USE, DATA, OR PROFITS; OR BUSINESS INTERRUPTION) HOWEVER CAUSED
AND ;
; ON ANY THEORY OF LIABILITY, WHETHER IN CONTRACT, STRICT LIABILITY, OR TORT
;
; (INCLUDING NEGLIGENCE OR OTHERWISE) ARISING IN ANY WAY OUT OF THE USE
OF THIS ;
; SOFTWARE, EVEN IF ADVISED OF THE POSSIBILITY OF SUCH DAMAGE.
,*****.

```