Master Thesis, Department of Geosciences

RAMMS::Rockfall versus Rockyfor3D in rockfall trajectory simulations at the Community of Vik, Norway

Dam Thanh Vo

UNIVERSITY OF OSLO

FACULTY OF MATHEMATICS AND NATURAL SCIENCES

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Dam Thanh Vo

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Department of Geosciences

Faculty of Mathematics and Natural Sciences

University of Oslo

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Summary

Assessment of advantages and limitations of rockfall models require in-depth-knowledge in the rockfall field, testing of model with field investigated data, as well as understanding rockfall mechanics. This thesis intends to give an overview of currently in-use rockfall models and summarizes the conclusions of researchers regarding the advantages and limitations of the models which were employed in their research projects. The main part of the thesis focused on the two complete rockfall models, RAMMS::Rockfall and Rockyfor3D. The two models were employed in back calculation analysis based on the field investigation data of a rockfall event that happened at Holaviki in the Community of Vik, Norway and was reported by Norwegian Geotechnical Institute (NGI). The two models were compared, one versus another, by looking at requirement input parameters, trajectory simulation approaches and the outcome results.

Each model has shown its advantages and also limitations for future developments. Applying those models in rockfall trajectory simulation is not a stand-alone approach, that does not disregard the important role of field observation data, case history data and scientist assessments that are essential for calibrating model parameters in order to improve simulation results.

Keywords: rockfall, runout, modeling, RAMMS::Rockfall, Rockyfor3D, trajectory, simulation, talus, topographical parameters.

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1. Introduction

1.1. Background and motivation statement

In the field of geohazards, rockfall normally has impacts on only small areas. However, the damage to the infrastructure or persons directly affected is difficult to predict and may be high with serious consequences.

Several rockfall models have been developed and applied in research and practice. The common main purposes of the models are to identify the rockfall susceptibility area, simulates the rockfall trajectories, which take into account the factors influencing the run-out distance including rock mass, slope characteristics and topographic conditions, and finally mapping the run-out areas. These models are relevant and much tools to assist in hazard mapping.

Assessment of advantages and limitations of a rockfall models require an in-depth-knowledge in the rockfall field, testing of model with field investigated data, as well as understanding about rockfall mechanics.

RAMMS::Rockfall and Rockyfor3D stand out to be the complete and advance models in simulation of rockfall trajectories. Both of them can simulate the falls in 3-Dimentions. While Rockyfor3D is being used in rockfall hazard assessments, the RAMMS::Rockfall with focusing in applying different rock shapes in the trajectory modelling is becoming a tool in simulation the trajectory of each individual rock after its releasing point.

Norwegian Geotechnical Institute (NGI), which is a leading international center for research and consulting within the geosciences, has valuable information and experiences about rockfall events in Norway. NGI is presently using Rockyfor3D for rockfall hazard assessments and rockfall prevention studies in Norway. NGI always invests in development and applying new tools in their research. Recently, with the new version of RAMMS::Rockfall, which was developed with new insights about impact of rock's shape parameters, NGI considers using RAMMS::Rockfall in their near future rockfall consultant services and studies. Therefore, the project of comparing Rockyfor3D versus RAMMS::Rockfall will have valuable contributions to NGI.

RAMMS development team had visited NGI in August 2014 to present their developments in the rockfall calculation algorithms. The idea of comparing RAMMS::Rockfall versus Rockyfor3D has got their fully supports. They are very interested in the outcomes of the project, which will be taken into account for the future development of new RAMMS::Rockfall versions. Using RAMMS::Rockfall for simulation runs at Holaviki in the Community of Vik, Norway was the first time ever the RAMMS::Rockfall trajectory simulation beta version model was tested on the Norwegian geological condition. The outcomes of this study will then place a first step in the long term future of employing such a model in Norway, especially at NGI.

With all the backgrounds and motivations, this master thesis intends to give detail assessments of the two rockfall models, RAMMS::Rockfall and Rockyfor3D. The models will be compared by looking at requirement input parameters, trajectory simulation approaches and the run-out areas.

The model calculations were done using RAMM::Rockfall Beta_1.6.23 and Rockyfor3D v5.2.1.

1.2. The objectives of the study

Field investigated information of rockfall events in the area called Holaviki in the Community of Vik, Norway, will be used as reference data for back calculation analysis by the two models RAMMS::Rockfall and Rockyfor3D. Several set of simulation parameters describing geology and topographic conditions of the areas will be employed in the scenario simulations. The important expectation results are to be able to back calculate the rockfall event happened in Holakivi as reported by NGI, published in 1995.

The two models will be compared by looking at the physical parameters that have been applied in calculation of rock motion and rock impact-contact with the terrain surface in order to evaluate the advantage and disadvantage of each model. Suggestions on how to improve the models are also expected.

2. Rockfall models – Why RAMMS::Rockfall versus Rockyfor3D

Published literatures in the recent years (1995-2013) on the field of rockfall models were reviewed to find the most modern rockfall models, which were employed in different studies and research projects. The following paragraphs describe shortly the characteristics of the most recent in-use rockfall models.

Rockyfor3D - Rockyfor3D is a simulation model that calculates trajectories of single, individually falling rocks, in three dimensions (3D). The model combines physically based, deterministic algorithms with stochastic approaches, which makes Rockyfor3D a so-called 'probabilistic process-based rockfall trajectory model'. Rockyfor3D can be used for regional, local and slope scale rockfall simulations (Dorren, 2012).

RAMMS::Rockfall - RAMMS::Rockfall module employs rigid body algorithms to model the run-out dynamics of single rock blocks over three dimensional terrain. This simulation model is currently being developed at the Center of Mechanics (Institute for Mechanical Systems, ETH Zurich) in close cooperation with SLF/WSL. The rock is modelled as a three-dimensional indestructible polyhedral rigid body which can come into frictional contact with a tessellated surface (Christen et al., 2012).

Slope Mass Rating (SMR) - The Slope Mass Rating is a parametric method that expresses the susceptibility to instability of a rock slope by means of a rating system, taking into account both the rock-mass quality and corrective factors depending on geometric relationships between joint sets and the slope face (Apuzzo et al., 2013).

The Matheson's graphical tests (MATHESON, 1983) are a useful method to identify type and number of possible fundamental mechanisms of instability (plane sliding, wedge sliding, direct and flexural toppling), considering a simplified calculation of the limit-equilibrium condition. It consists of four graphical overlays suitable for each mechanism of instability to be used together with stereo plots of discontinuities data (Apuzzo et al., 2013).

Numerical Manifold Method (NMM) - A complete rock failure process usually involves opening/sliding of preexisting discontinuities as well as fracturing in intact rock bridges to form persistent failure surfaces and subsequent motions of the generated rock blocks. The recently developed numerical manifold method (NMM) has potential for modelling such a complete failure process (Ning et al., 2012).

CONEFALL - Rockfall propagation areas can be determined using a simple geometric rule known as shadow angle or energy line method based on a simple Coulomb frictional model implemented in the CONEFALL. Runout zones are estimated from a digital terrain model (DTM) and a grid file containing the cells representing rockfall potential source areas. The cells of the DTM that are lowest in altitude and located within a cone centered on a rockfall source cell belong to the potential propagation area associated with that grid cell. In addition, the CONEFALL method allows estimation of mean and maximum velocities and energies of blocks in the rockfall propagation areas (Jaboyedoff and Labiouse, 2011).

Rockfall Analyst (RA) – RA, a three dimensional extension to GIS, includes two major parts: (1) 3D rockfall trajectory simulation and (2) raster modeling for spatial distribution of rockfalls. As most of rockfall simulation modules, a ‘‘lumped mass’’ or point approach is used in RA to simulate rockfall trajectories. However, because the spatial autocorrelation of factors affecting rockfalls (e.g. slope geometry, geology, vegetation, etc.), dominate the spatial correlation of rockfall events in terms of their run out extent, velocity and energy distribution, the spatial geostatistics-based raster modeling is used in dealing with the spatial distribution of rockfall frequency, energy as well as their uncertainty (Lan et al., 2007).

RocFall - (RocFall 4.0, 2000) is a useful computer program based on the laws of motion and collision theory which allows the path of rock blocks to be calculated. The kinetic energies, velocities, endpoints (fall out distances) and bounce heights at each point within a profile can also calculated. RocFall can also assist in determining remedial measures: the material properties of each slope segment can be changed and the analysis re-run, comparing the results. Information about the kinetic energy and location of impact on a barrier can help determine the capacity, size and location of barriers (Yilmaz et al., 2008). As the time of writing this thesis, the RocFall ver 5.013 was released as the latest version with new developments.

CADMA - it allows predictions to be made of fall trajectories and of the relevant parameters (energy, height of bounce, runout distance of the falling blocks) for the design of remedial works (Azzoni et al., 1995)

Flow-R - is a spatially distributed empirical model developed under Matlab®. Application of the model requires two distinctive steps based on a digital elevation model (DEM): (1) the source areas are first identified by means of morphological and user-defined criteria, and then (2) debris flows are propagated from these sources on the basis of frictional law sand flow direction algorithms. (Horton et al., 2013)

Other model like STONE (or HY-STONE as today new version) developed by Guzzetti et al. in 2002 that was mentioned in Yilmaz et al., 2008. Or Perla and the SFLM models were mentioned by Horton et al., 2013, and there are many more developed models. But due to time constraint, this thesis limited to the introduced models only. A more complete list of available rockfall models can be found in (Volkwein et al., 2011)

Literature authors divided rockfall trajectory models into different types or groups. Azzoni et al, 1995 roughly divided into two types: those considering the block either with no mass or with the mass concentrated in one point (kinematic and lumped mass methods, respectively), and those that consider the block as a body with its own shape and volume. The latter models are generally better than the former, as they are more capable of accurately reproducing the different phases of the fall phenomena.

Dorren, 2003 divided existing models in three groups: (1) empirical models, (2) process-based models and (3) Geographical Information System (GIS)-based models (Dorren, 2003).

Short definition of different types of rockfall models in Dorren, 2003:

- Empirical rockfall models are generally based on relationships between topographical factors and the length of the runout zone of one or more rockfall events. Sometimes these models are referred to as statistical models.
- Process-based models describe or simulate the modes of motion of falling rocks over slope surfaces.
- GIS-based models are those either running within a GIS environment or they are raster-based models for which input data is provided by GIS analysis. GIS-based rockfall models consist of three procedures. The first procedure identifies the rockfall source areas in the region of interest, the second determines the falltrack and the third calculates the length of the runout zone.

Volkwein et al., 2011 grouped existing models firstly according to their spatial dimensions: (1) two-dimensional (2-D) trajectory models, (2) 2.5-D or quasi-3-D trajectory models and (3) 3-D trajectory models, and secondly according to the underlying calculation principles (Volkwein et al., 2011).

Later on, in 2013, Leine et al. distinguished between four different types of rockfall simulation codes: (1)“horizontal” 2D approach, (2)“vertical” 2D approach, (3) 2.5D approach (being a concatenation of the latter two) and (4) 3D simulation approaches (Leine et al., 2013).

Volkwein et al., 2011 described rockfall model types by their spatial dimension as:

- 2-D trajectory model simulates the rockfall trajectory in a spatial domain defined by two axes. This can be a model that calculates along a user-defined slope profile that is defined by a distance axis (x or y) and an altitude axis (z). Such a profile often follows the line of the steepest descent.
- 2.5-D models, also called quasi-3-D models. These are simply 2-D models assisted by GIS to derive pre-defined fall paths. The key characteristic of such models is that the direction of the rockfall trajectory in the x,y domain is independent of the kinematics of the falling rock and its trajectory in the vertical plane.
- 3-D rockfall models are defined as trajectory models that calculate the rockfall trajectory in a 3-dimensional plane (x, y,z) during each calculation step.

Table 1: Main characteristics of a selection of currently in-use rockfall models

Models	Empirical	Process-based	GIS-based	Dimension 2-D	3-D	Approach
CADMA		●		●		Hybrid
CONEFALL		●		●		Lumped-mass
Flow-R	●			●		Lumped-mass
NMM		●		●		Lumped-mass
RAMMS::Rockfall		●	●		●	Rigid body
RocFall		●		●		Lumped-mass
Rockfall Analyst (RA)		●	●		●	Lumped-mass
Rockyfor3D		●	●		●	Hybrid

A **hybrid system** is a dynamic system that exhibits both continuous and discrete dynamic behaviour – a system that can both *flow* and *jump*

A **rigid body** is an idealization of a solid body in which deformation is neglected

Lumped mass just means assuming all the mass is concentrated in one rigid object

In Table 1, the rockfall trajectory models were grouped by computation base, rockfall trajectory dimension and approach. Most of rockfall trajectory models are process-based models. Flow-R utilizes both empirical studies and physical modelling.

Experimental methods include empirical studies and physical modelling. Those methods mainly consists of performing tests on scale models. That type of methodology is expensive and unsuitable for statistical and parametric analysis.

Even though, Azzoni et al., 1995 concluded that experimental methods are still very important, both for the study of the phenomenology and the assessment of the relevant physical parameters, not to mention the correct calibration of the mathematical models.

Most models analyze the falls in a 2-dimensional (2-D) space, no introduced model is 2.5-D. The 3-D analysis is more accurate but more expensive and time consuming. By the development of computer technology in the last 20 years, and the availability of powerful computers at moderate costs, the mentioned limitations have been overcome. The development of process-based and GIS-based models that utilize statistical and parameter analysis in simulation of the rockfall trajectory in 3-D has been in focus in the recent years.

Assessment of advantages and limitations of a rockfall models require an in-depth-knowledge in the rockfall field, testing of model with field investigated data, as well as understanding about rockfall mechanics. The thesis aims to summarize the conclusions of researchers in the studies when applying rockfall models in their research projects (Table 2).

Table 2: Summary the advantages and limitations of rockfall models

Models	Advantages	Limitations
CADMA (Azzoni et al., 1995)	• Simple to run • Provides clear and easily read graphical outputs, such as slope profiles with fall trajectories, histogram of velocities	• Block fracturing is not taken into account • Block falls along a trajectory not affected by those of the other blocks

Models	Advantages	Limitations
CONEFALL (Jaboyedoff and Labiouse, 2011)	• Suitable for large and rapid survey where the collection of require field data for kinematics bases modelling is not possible • Stand-alone solution	• Simple frictional model, assuming that block sliding along a slope • Strongly dependent on the slope morphology
Flow-R (Horton et al., 2013)	• Suitable for debris flow susceptibility mapping. • Low data requirement • Open to the user in terms of inputs and algorithms	• Volume and mass are not taken into account • Not suitable for individual event modelling • Cannot integrate local controlling factors and actual physical behaviors
NMM (Ning et al., 2012)	• It allows non-persistent discontinuities and can simulate both the opening/sliding along pre-existing discontinuities and the fracturing in intact rock • Simulate a complete rock failure process	• The rigid body rotation is not represented explicitly • Unexpected material domain area change occurs in rotation modelling
RAMMS::Rockfall (Leine et al., 2013)	• Influence of shape on the rolling behavior of blocks can be studied • Possible to describe the scarring effect of rock on terrain	• Cannot describe the scattering effect caused by collision with individual trees • No account for finite strength of trees
RocFall (Yilmaz et al., 2008)	• Ability to determine the current state of the rocks as they pass certain locations on the slope	• Difficult to establish spatial distribution in the exact coordinates in a global position • Manually transferring data to ArcGIS from RocFall
Rockfall Analyst (RA) (Lan et al., 2007)	• Using both raster and vector data • Capable of effectively handling distributed geometry and mechanical parameters • Can call geostatistical functions built in GIS environment	• No consideration of rock shape factors
Rockyfor3D (Corona et al., 2013) (Dorren and Seijmonsbergen, 2003)	• Calculate multi bounces within a pixel	• Only spherical shape is used to calculate the contact with terrain or trees • Gaps within forest stands were not taken into account in the input data

Conclusions from different studies confirm that the 3-Spatial Dimensions rockfall models compute high level of precision for calculation of trajectories, but they required very detailed level of input data for example block shape and its exact position before the release.

All rockfall models depends on data resolution and accuracy (especially the topographical data), as well as on parameter selection including rock sources and ground surface properties. Therefore, field observation data and case history data are essential for calibrating model parameters in order to improve simulation results.

The two most complete rockfall models are RAMMS::Rockfall and Rockyfor3D.

RAMMS::Rockfall takes into account 03 types of block shapes (Long, Equant, Flat) when looking at the influence of shape on the rolling behavior of blocks in the simulation method. A novel friction model, which involves a slippage dependent friction coefficient, has been introduced in RAMMS::Rockfall. Using this friction model, it is possible to describe the scarring effect of rocks on the terrain, i.e. rocks tend to plough into the ground material, slide, and then lift off (Leine et al., 2013).

Rockyfor3D has the possibility to use different rock forms like rectangular, ellipsoidal, and spherical and/or disc type block forms as input for the simulations. This block form determines 1) how the block volume (and consequently its mass) and 2) how the moment of inertia is calculated on the basis of three defined block diameters d1, d2 and d3. For calculating the block position, the rebound on the slope surface and impacts against trees, Rockyfor3D always uses a spherical shape (Dorren, 2012). Rockyfor3D, on the other hand, has advantages on calculation the impact against a tree, when a falling block against a tree, it loses a fraction of its kinetic energy.

Therefore, *RAMM::Rockfall Beta_1.6.23* and *Rockyfor3D v5.2.1* were selected to further study against each other in the back analysis calculations.

3. Model testing areas

Testing the models with a full scale terrain area is necessary. The models were applied on the area named Holaviki, located on the southern side of the Sognefjord. Sognefjord, located in Sogn og Fjordane County in Western Norway, is the largest fjord in Norway and the longest open (ice-free) fjord in the world. The fjord runs through many municipalities. Holaviki area are located in the Vik municipality in the Sognefjord region (see Figure 1).

Figure 1: Holaviki areas in the Sognefjord region, Western Norway

The Holaviki is a small village located on a small flat area with mountain on one side and fjord water on the other side. There is a main road Fv92 runs through the area.

NGI report no. 585910-3 (December 1995) – Natural rockfalls – Descriptions and calculations by Ulrik Domass (Domaas, 1995) described a rockfall event in Holaviki. A rockfall (in phyllite) was released due to heavy rainfall.

The reason selecting this event is because very seldom it is possible to study full scale rockfall in action, but it has been possible for NGI to do the investigation in this Holaviki event. Otherwise mostly the investigation happens on the situation results after rockfalls.

Figure 2: Holaviki area - orthophoto

The historical data of this Holaviki rockfall event will be rebuilt as input data into the two testing model RAMMS::Rockfall and Rockyfor3D. The main purpose is to find parameters to be used in the models from the full scale natural rockfalls. The scatter of these parameters can be used to calibrate models.

4. Input data requirements - RAMMS::Rockfall versus Rockyfor3D

4.1. Digital Elevation Model data (DEM)

Both RAMMS::Rockfall and Rockyfor3D require rasterised DEM which describes the topography of the study area in three dimensions as mandatory input data for the simulations. The preferred resolution lies between 1m to 10m. The DEM also define the project boundary coordinate. From the DEM, Rockyfor3D calculates the slope and aspect map. Additional to that, RAMMS::Rockfall calculate curvature and contour plot of the area with the input DEM.

4.2. Release rocks

There are differences in defining release rock in the two models. In RAMMS::Rockfall, user can define release rock either as point (X,Y) or as line (X1,Y1);(X2,Y2);… with distance between release points depends on the DEM resolution.

While, in Rockyfor3D the release rock is defined by a raster which has same size and resolution as input DEM. Value 0 (zero) will be assigned for the cells that are not source cells and rock density values (2500-3000kg/m^3) will be assigned for cells where a block from those cells will be simulated.

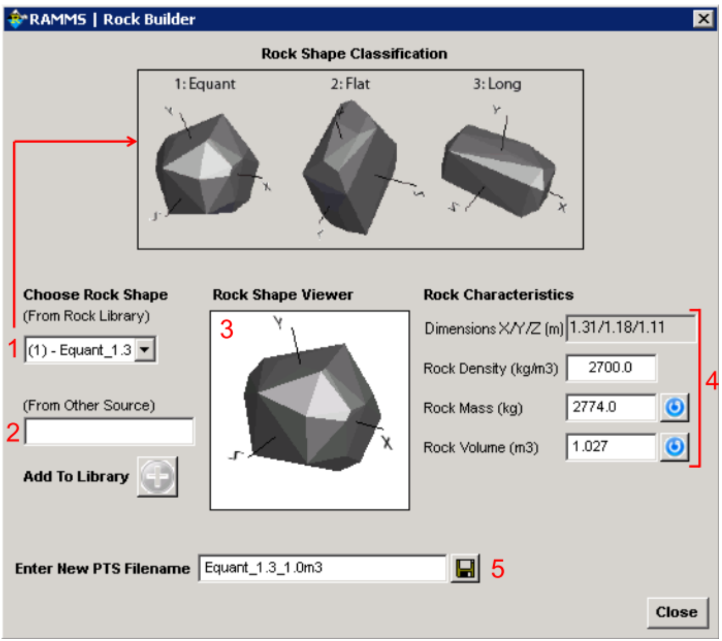


Figure 3: Rock Builder tool in RAMMS::Rockfall (source (Bartelt et al., 2013))

Another difference between the two models in term of release rock is that RAMMS::Rockfall defines release rock as point or line while the Rockyfor3D consider release rock as areas (could be only one cell or many cells).

4.3. Rock body

4.3.1. Form of rock

RAMMS::Rockfall introduce an input rock to the model as a cloud of points. Points are given in (x,y,z) format. A convex hull of the rock-body's points cloud is created, in doing so RAMMS::Rockfall creates an entirely convex body of the rock; concavities are closed over in the process.

Rock Builder in RAMMS::Rockfall assist users to define the rock body in 03 typical shapes Equant, Flat and Long (Bartelt et al., 2013). The users can adjust the Rock volume and Rock Mass to match the release rock in the natural rockfall event.

Rockyfor3D, in another hand, require the input data to define the rock body by 03 raster files represent values of 03 dimensions (d1.asc, d2.asc, d3.asc). Plus 01 raster (blshape.asc) value (0-4) to define rock shapes

0 - No block form / no source cell defined
1 - Rectangular block (all three diameters can be completely different)
2 - Ellipsoidal block (all three diameters can be completely different)
3 - Spherical block (all three diameters are identical)
4- Disc shaped block (smallest diameter is max. 1/3 of the other two block diameters, which are rather comparable in size)

4.3.2. The random of rock at the release stage

In RAMMS::Rockfall the contact between the falling rock and the terrain is determined by the contact of the rock corner points with the terrain surface (described in detail in subchapter 5.2), and since the release rock in RAMMS::Rockfall is form by a cloud of points, it is important to know the Initial Rock Orientation (phi, theta, psi) for the first contact calculation. RAMMS::Rockfall gives the possibility to the users to run the multiple Rock Orientations simulation by allowing user to define number of random orientations to change the Initial Rock Orientation, the Phi, Theta, Psi can be varied between +/-10 – 20 degrees randomly by RAMMS::Rockfall. The number of changing time is equal to user-define number of random orientations.

On the other hand, Rockyfor3D allows user to run multiple simulations by randomly change the volume of the rock. In Rockyfor3D, the three rock dimensions defined in each source cell are varied uniform randomly with a predefined % (based on the defined volume variation between ±0% and ±50%) before each simulation. This random variation is always identical for all three block dimension values for one single simulation. This means that if the volume variation is set to 5%, then all 3 block dimensions are randomly decreased or increased with a value between 0 and 1.639%.

4.4. Terrain material

When in contact with the terrain surface, the magnitude of energy absorption of falling rock very much depends on the type of terrain material that the rock gets into contact with.

RAMMS::Rockfall groups the terrain type by the hardness of terrain material (extra soft → extra hard). Each terrain type will associate with a set of (mu-min, mu-max, beta, kappa, epsilon, ground drag) (see Table 4 on page 21)

In the input step, user can either specify the overall terrain material for the study area or insert polygon shape files for all the different and important terrain materials inside the area of interest and select the terrain hardness level for for each polygon.

Rockyfor3D suggested 07 Soil Type – value (0-7) of underground, elasticity of the ground, mapped by polygon before converting to raster (see Table 5 on page 24 for soil type description). For each soil type Rockyfor3D assigns a mean value of the normal coefficient of restitution (R_n), which is a component in the formula to calculate Vn – Normal Velocity (see detail in 5.2.3.2 on page 22) .

In additional to the soil type, Rockyfor3D introduce the possibility to use 03 raster files to describe the slope surface roughness (rg70.asc, rg20.asc, rg10.asc) represent rocks which form obstacles for falling block. The 03 raster files, in respectively order, correspond to the height of a representative obstacle (MOH) in meter that a falling rock encounters in representative 70%, 20%, and 10% of the cases during a rebound in the defined polygon.

Table 3: Size of the surface roughness and the related Rg values (source:(Dorren, 2012))

Size of the surface roughness (MOH)	Possible Rg values (in m)
No roughness, obstacles absent	0
> 0 – 10 cm	0.03, 0.05, 0.08, 0.1
> 10 – 50 cm	0.15, 0.2, 0.25, 0.3, 0.35, 0.4, 0.5
> 50 cm – 1 m	0.6, 0.7, 0.8, 0.9, 1

Size of the surface roughness (MOH)	Possible Rg values (in m)
> 1 – 2.5 m	1.1, 1.2, 1.3, 1.4, 1.5, 2, 2.5
> 2.5 – 10 m	3, 4, 5, 6, 7, 8, 9, 10
> 10 m	100

Thus the Rg values given by the three size probability class rg70, rg20, and rg10, represent values that are used in respectively 70%, 20% and 10% of the rebound calculations.

For example a terrain which has Soil Type value 6 (bed rock) will have a set of rg70, rg20, rg10 suggested by Rockyfor3D as 0, 0, 0.05 respectively. According to Table 3 and because of both rg70 and rg20 is equal to 0 (zero), it means that 90% the falling rock will not face any obstacles and 10% it will hit obstacle rocks which have MOH about 0.05m (or 5cm). The input surface roughness values have to more or less precise.

4.5. Obstacles – Forests/Swamps/Waters

Input data requirements in RAMMS::Rockfall for forests or swamps or water areas represent by polygons with layer height (m) and drag value (kg/s). RAMMS::Rockfall applies a linear vicous damping force which is acting only within layer height.

Forest in Rockyfor3D is described by tree file [X,Y, DBH (cm)]
whereas:

- (X,Y) – coordinate of the tree
- DBH (stem diameter at breast height in cm)

Rocky3D also requires a raster file called “conif_percent.asc” to define the percentage of coniferous tree in each cell.

Alternatively, Rockyfor3D can also use 04 raster maps to convert information to a tree file as above.

- nrtree.asc to describe no. of stems/ha
- dbhmean.asc – mean DBH(0-250cm)
- dbhstd.asc – standard deviation of DBH (0-250cm)
- conif_percent.asc

4.6. Input data requirement conclusions

In general, RAMMS::Rockfall provide integrated tools that assist users to build necessary input data requirement, the input data format for RAMMS::Rockfall could be in any types points, lines, polygons or raster. While Rockyfor3D requires almost only as raster format and users have to use third-party tool (ArcGIS, SAGA-GIS,…) to create necessary input data.

RAMMS::Rockfall has the advantage with rock builder tool, which allows users to build different form of rock using cloud of points, by that way, the built rocks precise to the real rocks. On the other hand, Rockyfor3D gives possibility to build terrain surface in most appropriate way by allowing users to describe the roughness of the slope surface with the height of a representative obstacle of the surface. By another word, because of well computation what happens at, during and after the contact of the falling rock and terrain surface is crucial for the next computation steps, both the two models try to allow users to provide as accurate as possible the information to calculate the contact between falling rock and the terrain surface. Field investigation is necessary to collect such information.

Another main difference between the two models is the randomly change of falling rock for each simulation. RAMMS::Rockfall uses same input rock form but will rotate Initial Rock Orientation for each simulation, while Rockyfor3D will randomly change the volume of the rock with no influent on the rock form because Rockyfor3D always use spherical shape for calculating the rock position, the rebound on the slope surface and impacts against tree.

Regarding forest impact, Rockyfor3D has advantage when using provided input data to create tree file with tree location (X,Y) and BDH (stem diameter at breast height in cm). That allows users with enough field investigation data to build close-to-reality forest as obstacle objects for the falling rock. While RAMMS::Rockfall consider forest as a drag layer with same height as forest height and applies a linear vicous damping force with the drag layer height (more detail described in 5.2.4).

5. Motions of rock in relation with physical parameters - RAMMS::Rockfall versus Rockyfor3D

The outcomes of a model run are normally the combination results of input data setup and the calculation algorithms. In order to compare and identify the differences when applying the models on the full scale event, one should also study the calculation algorithms of the two models. The following subchapters will describe the calculation algorithms of the two model at each typical motion step of a rockfall event.

5.1. Free flight

In RAMMS::Rockfall, the rock is assumed to be a 3-D rigid body, with three translational and three rotational degrees of freedom.

First RAMMS::Rockfall consider the rock in free flight and deal with the contact forces later. In free flight the parameters that govern the motion are the mass, three moments of inertia, the rocks three translational and three rotational velocities.

The rock motion is also governed by gravitational force, which act globally, and drag force, which represent the effects of trees. Along with gyroscopic forces, which can cause irregular-shape rocks to become rotate around a rolling axis.

In Rockyfor3D, as described in Dorren, 2012, Rockyfor3D considers the flight of rock as parabolic free fall, which is calculated with a standard algorithm for a uniformly accelerated parabolic movement through the air. The parameters that govern the parabolic free flight are the initial velocity of the rock, the angle of projection and gravitational force with respect to the local slope. When the rock reaches a vertical velocity of zero at the maximum height of free flight path then gravitational force will take place and accelerate the rock downward.

Since Rockyfor3D uses only spherical rock in calculation of the rebound on the slope surface and impacts against trees, the gyroscopic forces is neglected.

5.2. Contact, during contact and rebound on the terrain surface

5.2.1. Contact

In RAMMS::Rockfall, contact forces and frictional contact forces are external forces that change the direction of the falling rock.

The contact of the falling rock is detected by continually measuring the vertical gap length between the rock and the terrain projections. When the gap (g_N in Figure 4) is larger than 0 there is no contact, when it is less than 0 there is contact and the contact forces are computed.

Contact forces are modeled as hard unilateral constraints with Coulomb friction using non-smooth contact dynamic approaches (Bartelt et al., 2013). For the case of contact the rock motion is determined by direction of contact forces and a number of active contact forces depending on orientation and kinetics at the point of contact (contact between rock body's corner points (P) and the terrain projection (Q) as in Figure 4). The combination of these forces and force directions allows the complex rotations and trajectory deviation to be simulated.

Contact point Q has a normal contact force component (n) and two tangential components (t1, t2). The contact force (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 (Bartelt et al., 2013).

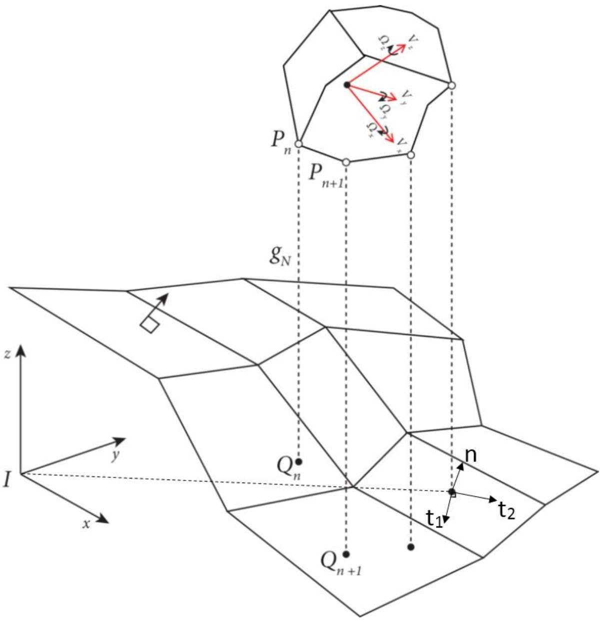


Figure 4: Contact detection in RAMMS (modified from (Bartelt et al., 2013))

To determine the resultant force direction, the relative velocity between the contact points P and the terrain Q has to be calculated. The velocity of contact point P includes translational velocity with respect to the body's center of mass and its angular velocity in the fixed body frame; for which P also has a fixed position vector relative to the center of mass. In other words, RAMMS::Rockfall consider the rotational speed of the rock at contact.

Because the forces (with a direction) are then applied at rock corner points, which are away from the center of mass to a rock body with three degrees of translational and rotational freedom, torques and moment arms occur to generate rotations and rebounds that represent the true mechanics of an impact.

In Rockyfor3D, at contact position, the incoming velocity in the horizontal plane xy (V_{hor}) and the one in the vertical plane z (V_{vert}) are converted into an incoming normal V_n and tangential velocity V_t (with respect to the local slope). Then, the penetration depth of the block at the impact location is calculated (Figure 5).

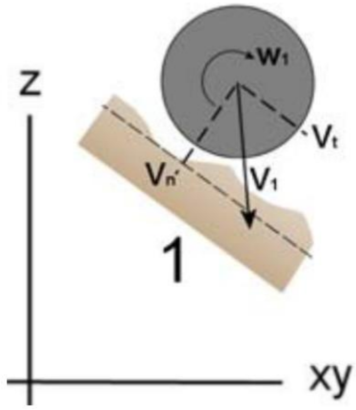


Figure 5: Contact algorithm used by Rockyfor3D (modified from Fig 6 in (Dorren, 2012))

5.2.2. During contact

In RAMMS::Rockfall, during contact, two physically different forces oppose the motion of a falling rock: sliding friction and drag.

Sliding friction in RAMMS::rockfall

A Coulomb-type friction acts at corner points of the rock's surface that are in contact with the ground; it is a sliding friction associated with the distance the rock slides on the ground. When there is no contact, this sliding 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. Identify the parameterization of the friction force is importance because it controls the time when rock slides, rolls or jumps.

On the other hand, drag force acts at the rock's center of mass in the direction opposite to the rocks movement (velocity), this force creates no rotational moments. There are two drag forces in the RAMMS::Rockfall model. The first represents vegetation drag; the second represents the viscoplastic drag due to terrain deformation during ground contact.

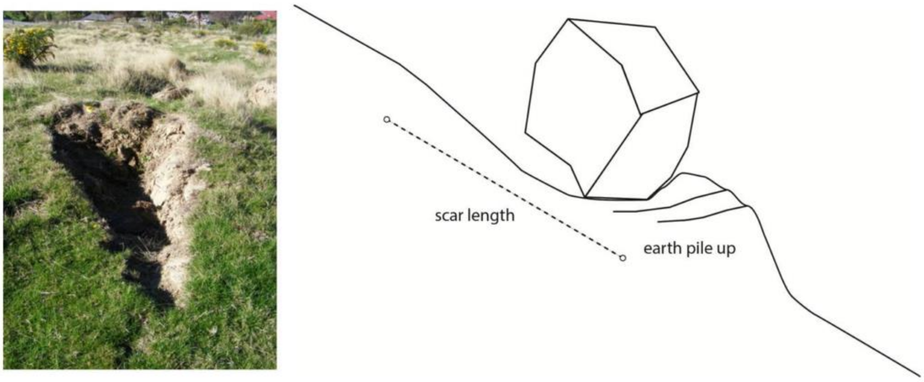


Figure 6: Illustration of slippage motion in RAMMS::Rockfall (source (Bartelt et al., 2013))

During the contact of rock on the terrain surface, in some cases, the rock contact can be with soft soils that easily deforms under contact. In such contacts there is a degree of penetration and sliding of the rock-body as the rock ploughs into the earth cover accumulating material behind it leaving behind distinctive impact scars in the terrain. For that, RAMMS::rockfall introduces a slip dependant friction that acts during sliding and accounts for the increase in friction due to material accumulation behind the rock body as it slides through the impact (see Figure 6). Detail about how the slip dependant friction acts will be described in 5.2.3. Rebound subchapter.

Drag force in RAMMS::rockfall

As mentioned above there are two drag forces, the vegetation drag or forest drag which will be described in subchapter 4.4.2 Forest drag. During the contact of the rock and the terrain surface there is the viscoplastic ground drag.

The viscoplastic ground drag is introduced to account for the viscoplastic deformation that occurs in terrain soils under rock impact. Viscoplastic ground drag acts when the rock is in contact with the ground ($g_N < 0$) as the rock is sliding on the terrain surface ($s > 0$). The viscoplastic ground drag force F_v is proportional to the square of the rock velocity V_s^2 as well as the mass of the rock m. In another words, the heavier and faster the moving rock the more drag acts on the rock, because they penetrate the ground surface.

The viscoplastic ground drag force is proportional to the rock's total kinetic energy. The ground drag coefficient varies between 0.0 1/m (hard surface terrain) and 1.0 1/m (soft surface terrain). RAMMS::Rockfall introduces ground drag coefficient values for different terrain surface type as in Table 4 in 5.2.3. Rebound chapter below.

In Rockyfor3D, during contact, penetration depth D_p is also introduced with the maximum depth equals the simulated block radius (see Figure 7). If the penetration depth is calculated, the calculation of rebound can be initiated.

The required input parameters to calculate penetration depth in Rockyfor3D are:

- Normal coefficient of restitution (R_n)
- Diameter of the block (d in m)
- Mass of the rock (RockMass in kg)
- Impacting velocity of the falling block (V in m.s-1)
- Indentation resistance of impacted material (in MPa), indentation resistance has values between 1-5 MPa for fine soil and 200-250 MPa for bedrock

- Density of impacted material (in kg/m^3), values between 1500 kg/m^3 for fine soil and 2500 kg/m^3 for bedrock

And the used of 2 constants:

- k = 1.207 (dimensionless constant accounting for the spherical block shape)
- B = 1.2 (dimensionless compressibility parameter of the impacted material)

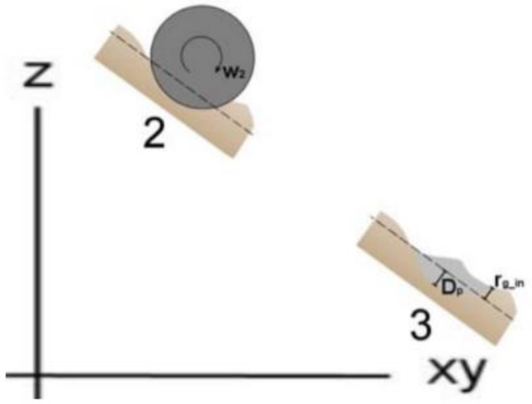


Figure 7: Penetration Depth algorithm in Rockyfor3D (modified from Fig 6 in (Dorren, 2012))

The penetration depth was introduced in both RAMMS::Rockfall and Rockyfor3D. In additional to the slip dependant friction was introduced in RAMMS::Rockfall to simulate the sliding of the rock-body as it ploughs into the soft earth cover.

5.2.3. Rebound

5.2.3.1. Rebound in RAMMS::Rockfall

The rebound in RAMMS::Rockfall happens when slip dependant friction reach its maximum values. Each terrain surface type will be assigned a minimum and a maximum slip dependant friction (see Table 4).

The slip dependant friction is an extension of the Coulomb friction model in which the friction value μ is made dependant on the slip distance (s) travelled by the center of mass μ(s) (Figure 8).

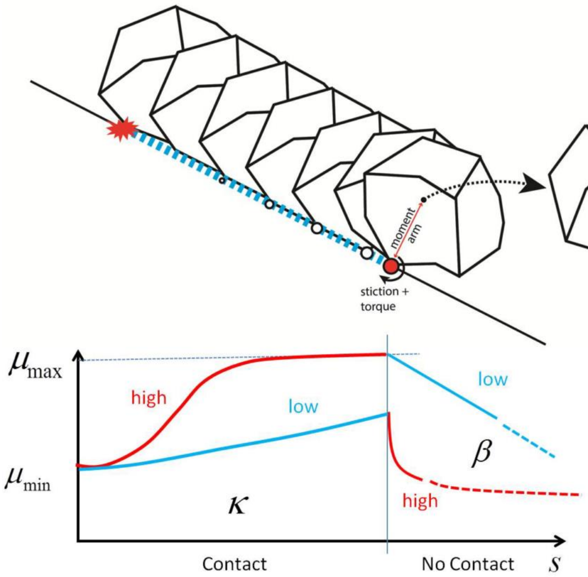


Figure 8: Contact frame of rock on terrain (source (Bartelt et al., 2013))

The dependence of the friction coefficient on the slip distance (s) is:

$$\mu_{(s)} = \mu_{min} + \frac{2}{\pi}(\mu_{max} - \mu_{min}) \arctan(Ks) \qquad \text{[eq. 7 in (Bartelt et al., 2013)]}$$

The slip distance (s) is a transition state variable which has a time-evolution. As long as there is one active contact with normal contact force (n) > 0 between terrain and rock, distance (s) grows by integrating the norm of the center of mass velocity v_S of the rock.

The slip dependant friction $\mu_{(s)}$ therefore increases with the slipping distance of the center of mass. There are 02 parameters *K* and β that control the act of the friction.

- The parameter *K* (sliding friction proportionality constant) controls how quickly the friction increases from μ_{min}, to μ_{max}.
- The parameter β controls how quickly the friction is released as the rock departs the ground scar.

The parameter β is linked to the penetration depth of the rock into the ground. Larger penetration depths (softer materials) are associated with smaller β values.

If β is large, friction is immediately removed as the rock moves away from the ground. Conversely, when β is small, sliding friction can act, even after the rock is no longer in contact with the ground that is to reflect the physical behavior that the rock gradually has to overcome the heap of ground material in front of it.

RAMMS::Rockfall introduces friction values as in Table 4 for different type of terrain surfaces.

Table 4: Terrain types and physical parameters used in RAMMS::Rockfall

	μ_{min}	μ_{max}	β (s^{-1})	*K* (m^{-1})	Ground drag	Characteristics
Snow	0.1	0.35	150	2	0.7	Snow-Gliding
Extra Soft	0.2	2	200	1	0.9	
Soft	0.25	2	185	1.25	0.8	
Medium Soft	0.3	2	175	1.5	0.7	

	μ_{min}	μ_{max}	β (s^{-1})	*K* (m^{-1})	Ground drag	Characteristics
Medium	0.35	2	150	2	0.6	
Medium hard	0.4	2	125	2.5	0.5	
Hard	0.55	2	100	3	0.4	
Extra hard	0.8	2	50	4	0.2	Bedrock

5.2.3.2.Rebound in Rockyfor3D

The rebound velocities of the rock after contact is calculated in Rockyfor3D after the computation of penetration depth (D_p) during contact.

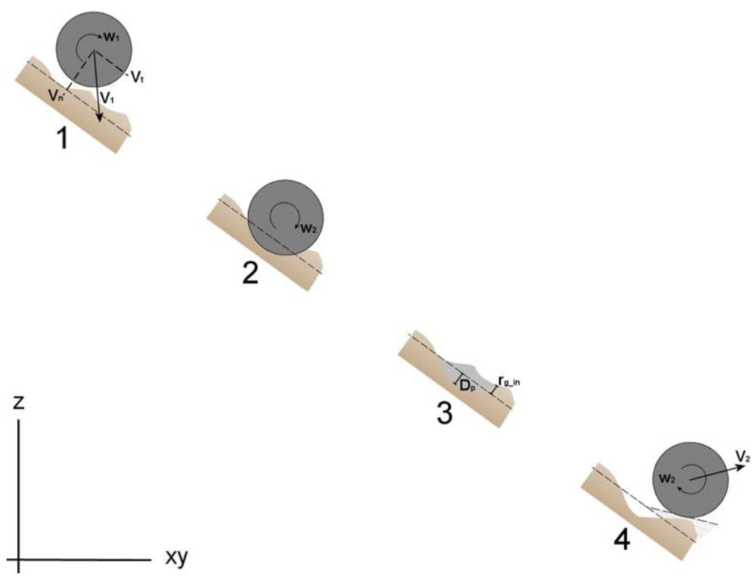


Figure 9: The rebound as represented by the algorithms used by Rockyfor3D (Dorren, 2012)

The velocity of the rock after rebound (V_2) has three components, normal velocity component (V_n) and tangential velocity component (V_t) and rotational velocity (V_{rot}).

V_t - Tangential velocity component

In order to derive tangential velocity component (V_t), tangential coefficient of restitution (R_t) has to be obtained first. R_t is determined by the composition and size of the material covering the surface and the radius of the falling block itself. Therefore, in Rockyfor3D, R_t is calculated using the algorithm based on the representative obstacle height at the slope surface (MOH in meter), the penetration depth (Dp in meter) and the radius of the falling block (R in meter).

$$R_t = \frac{1}{1+((\mathrm{MOH}+\mathrm{Dp})/\mathrm{R})}$$ *[eq. 7 in (Dorren, 2012)]*

Rockyfor3D users will make polygon maps with mean diameters of the material covering the surface (MOH) classified in different diameter classes, the R_t then be derived from those maps.

The user needs to map three MOH classes that are representative for the mean obstacle height a rocks encounters during 70%, 20%, and 10% of the rebounds in a mapped polygon.

Then, the rebound algorithm in Rockyfor3D chooses the MOH on the basis of the three cover classes in the polygon using a random number. Thus the values given by the three size probability classes rg70, rg20, and rg10, represent values that are used in respectively 70%, 20% and 10% of the rebound calculations.

The values rg70, rg20, rg10 for different terrain surface types can be found in *(Dorren, 2012) – Annexe II. Examples of parameter values for different slope surface types*.

Before the actual calculation of V_{t2}, Rockyfor3D randomly varies the value of the calculated R_t with +/- 10% to represent the variance in surface roughness observed in nature. The same accounts for the normal coefficient of restitution (Rn), which is used for calculating the normal velocity component of the block after the rebound (Dorren, 2012).

Then the tangential velocity component (V_t) is calculated by:

$$V_{t2} = \sqrt{\frac{R^2 * (I * V_{rot1}^2 + RockMass * V_{t1}^2) * R_t}{I + RockMass * R^2}} \qquad \textit{[eq. 8 in (Dorren, 2012)]}$$

where:

- V_{t1} = the tangential velocity component of the block before the rebound
- V_{rot1} is the rotational velocity before the rebound
- I is the moment of inertia of defined block form

V_n - Normal velocity component

The normal coefficient of restitution (R_n), which is used for calculating the normal velocity component of the block after the rebound is suggested in Rockyfor3D for 07 soil types (see Table 5). Each soil type has a representative mean R_n values. Detail about the normal coefficient of restitution (R_n) value for each soiltype can be found in *(Dorren, 2012) – Annexe II. Examples of parameter values for different slope surface types.*

V_{n2} - Normal velocity component after the rebound is calculated by:

$$V_{n2} = \frac{-V_{n1} * R_n}{1 + (abs(V_{n1})/9)^2} \qquad \textit{[eq. 9 in (Dorren, 2012)]}$$

Where,

- V_{n1} is the normal velocity component of the block before the rebound
- R_n is the normal coefficient of restitution

According to (Dorren, 2012), the factor $(abs(V_{n1})/9)^2$ adjusts for the decrease in normal coefficient of restitution as the impact velocity increases. This factor represents a transition from more elastic rebound at low normal velocities to much less elastic rebound caused by increased fracturing of the block and cratering of the slope surface at higher normal velocities. As such, the model indirectly accounts for the effect of the impact angle on the character of the rebound.

Table 5: The soiltypes used by Rockyfor3D and the related Rn values (source:(Dorren, 2012))

Soiltype	General description of the underground	Mean R_n Value	R_n Value Range
0	River, or swamp, or material in which a rock could penetrate completely	0	0
1	Fine soil material (depth > ~100 cm)	0.23	0.21 – 0.25
2	Fine soil material (depth < ~100 cm), or sand/gravel mix in the valley	0.28	0.25 – 0.31
3	Scree (Ø < ~10 cm), or medium compact soil with small rock fragments, or forest road	0.33	0.30 – 0.36
4	Talus slope (Ø > ~10 cm), or compact soil with large rock fragments	0.38	0.34 – 0.42
5	Bedrock with thin weathered material or soil cover	0.43	0.39 – 0.47
6	Bedrock	0.53	0.48 – 0.58
7	Asphalt road	0.35	0.32 – 0.39

V_{rot} – Rotational velocity component

The rotational velocity after the rebound V_{rot2} is calculated with:

$$V_{rot2} = \min\left(\frac{V_{t2}}{R};\ V_{rot1} + \frac{(V_{t1} - V_{t2})*2}{5*R}\right)$$ *[eq. 10 in (Dorren, 2012)]*

Slope angle after rebound

(Dorren, 2012) explained how Rockyfor3D computes the slope angle at the position of the rebound. Rockyfor3D uniform randomly decreases the slope angle at the position of the rebound during each rebound, however, the maximum decrease of the slope angle is fixed to 4°. Rolling is represented by a sequence of short-distance rebounds with a distance in between that is equal to the radius (R) of the block and an absolute minimum distance of 0.2 m. These last two conditions only account for slopes with a gradient between 0° and 30°.

5.2.4. Forest Impact

5.2.4.1. Forest-Vegetation Drag in RAMMS::Rockfall

In RAMMS::Rockfall, the forest is parameterized by the effective height of the vegetation layer (Z_h) as well as the drag coefficient ($\hat{C}_f$). Those parameters are user-defined and are assigned to each forest area identified by user and added in the model simulation (see Table 6).

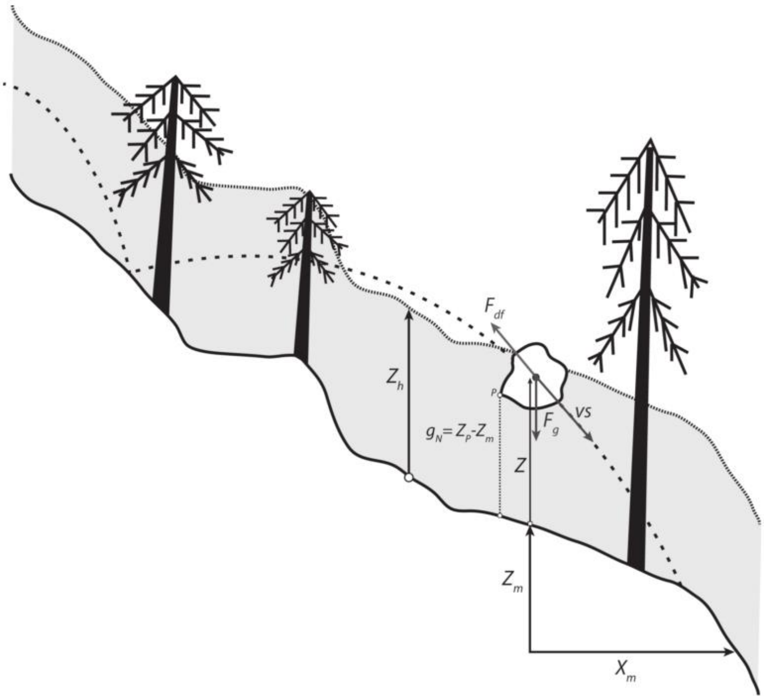


Figure 10: Illustration of forest drag used in RAMMS::Rockfall (source(Bartelt et al., 2013)

The effective height of the vegetation layer is estimated roughly corresponding to the height of the forest. This effective height will define the drag layer height (Z_h). When the rock's center of mass it is located within the drag layer, a resisting force will acts on it. This force is linearly proportional to the rock velocity V_s (Figure 10) and given by:

$$F_{df} = -C_f.V_s$$ *[eq. 3.10 in (Bartelt et al., 2013)]*

With $C_f = \hat{C}_f$ when the rock's center of mass is below Z_h ($Z<Z_h$), otherwise $C_f = 0$

Table 6: Parameters of different forest types used in RAMMS::Rockfall

Forest type	**Effective forest height (Z_h)(m)**	**Drag coefficient ($\hat{C}_f$)**
Light forest	5	1000
Medium forest	5	1500
Dense forest	5	2000
Lake/River/Moor	5	50000

5.2.4.2. Forest Impact in Rockyfor3D

In Rockyfor3D, to account for the impact of forest on the falling rock, the impact position on the tree stem and its influence on the energy dissipation during the impacts need to be calculated. Parameters that is used in the calculation are the diameter of the impacted tree, the tree type (coniferous or broadleaved) and the block energy.

The model user has to provide the positions (in x- and y-coordinates), diameter (in cm) at breast height of the trees (DBH) and the tree types (coniferous trees or broadleaved trees) in the direct surrounding of the simulated rock.

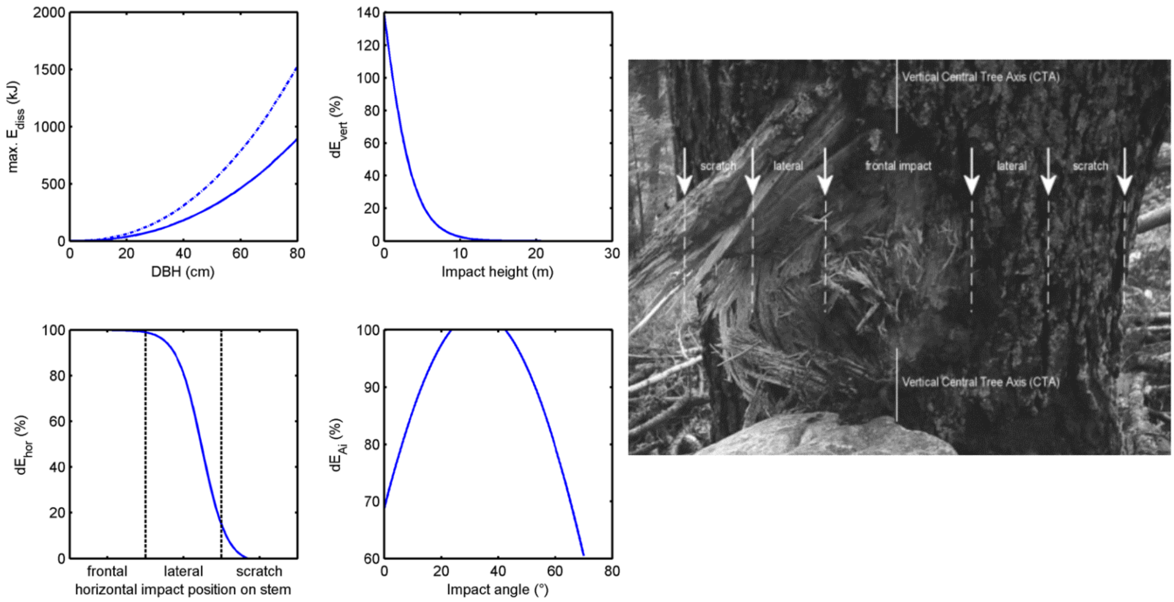


Figure 11: Visualization of the fours functions for calculating the impact against tree. The upper right graph is calculated with a tree height of ~13 m (DBH = 20 cm) (source: (Dorren, 2012))

If an impact against a tree takes place, the rock loses a fraction of its kinetic energy according to four main functions, which are visualized in Figure 11:

- Maximum amount of kinetic energy **(E_{dissM})** be absorbed by the tree.

  E_{dissM} = FE_ratio *38.7*DBH$^{2.31}$ *[eq. 11 in (Dorren, 2012)]*

  with FE_ratio = 0.93 for coniferous trees and 1.59 for broadleaved trees.

- The effect of the horizontal position **(d_{Ehor})**

  $$d_{Ehor} = -0.046 + \frac{0.98+0.046}{1+10^{\left(0.58-\left(\frac{(pi-CTA)}{0.5}*DBH\right)\right)*(-8)}}$$ *[eq.12 in (Dorren, 2012)]*

  with $pi - CTA$ = horizontal distance between the impact and the vertical central axis (in m)

- The effect of the vertical position, or impact height **(d_{Evert})**

  $$d_{Evert} = 1.62 * \left(\frac{1}{1+e^{18.04*(Z_i/H_{tree})+0.02*DBH-2.35}} - \frac{1}{1+e^{15.69+0.02*DBH}}\right)$$ *[eq. 14 in (Dorren, 2012)]*

  with Z_i is vertical position of the impact and H_{tree} = 1.22*DBH$^{0.8}$ which is according to *(Dorren, 2012)* is theoretical height of the tree based on the analysis of thousands of measured tree throughout the Apls.

- The impact angle (in degrees) of the rock with respect to the vertical standing tree **($d_{E\alpha\_imp}$)**

  $$d_{E\alpha\_imp} = \min\left(1;\ \left(1.03 * \sin\left(1.46 * \frac{\min(\alpha_{imp};70)}{180^o} * \pi\ +\ 0.73\right)\right)\right)$$ *[eq. 15 in (Dorren, 2012)]*

The total final amount of energy dissipated by the tree (E_{dtree}) (in kJ) is calculated by:

$E_{dtree} = E_{dissM} * d_{Ehor} * d_{Evert} * d_{E\alpha\_imp} / 1000$ *[eq. 16 in (Dorren, 2012)]*

In the calculation of impact against tree, while the RAMMS::Rockfall only considers forest as a homogenously distributed friction layer which acts as linearly proportional to the rock velocity V_s (in the opposite direction), on the other hand the Rockyfor3D, treats the impact against dependent on horizontal and vertical position of contact along with the angle of contact. Even more, Rockyfor3D looks at position of trees in the forest with individual x- and y-coordinates together with the diameter of the tree stem at breast height.

6. Back calculation analysis of rockfall trajectory – RAMMS::Rockfall versus Rockyfor3D

A rock fall event with rock path, run-out distance and deposited rocks data from the NGI report (Domaas, 1995) was used as a reference for the back analysis calculation using the two model RAMMS::Rockfall and Rockyfor3D.

The main purpose is to calibrate input parameters for the models to best fit the field conditions and try to simulate the rockfall trajectories that best match the ones mentioned in the NGI report.

In order to evaluate the results by using back calculation analysis approach, the input data set need to be built in equivalent for both the two models RAMMS::Rockfall and Rockyfor3D.

6.1. Input data for model simulation

6.1.1. Holaviki - DEM

The 5m resolution DEM data for Holaviki indicates the highest elevation at 1068,61m and lowest at 0m (sea level).

Figure 12 shows DEM in 5m resolution in combination with orthophoto area and derived slope data for Holaviki.

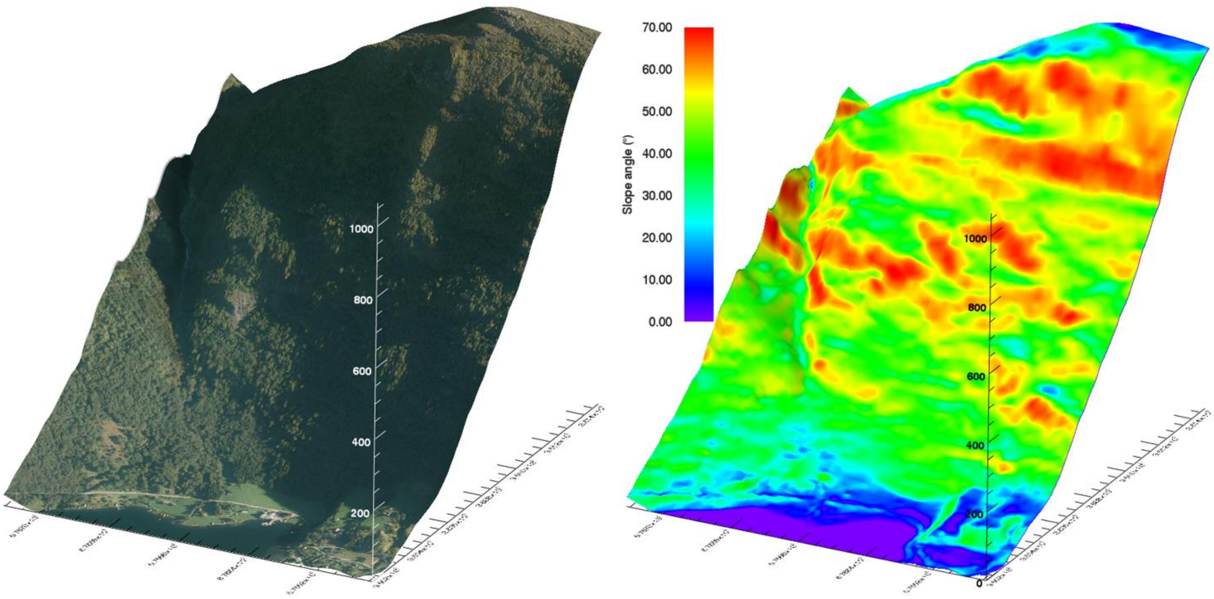


Figure 12: Holaviki DEM (left) and slope (right)

Input DEMs data for the two models were prepared as raster data with same resolution and exactly with the same model domain.

6.1.2. Holaviki – Terrain Characteristics

The Holaviki is covered mostly by forest which begins from the talus toe and runs up to the mountain. Between talus toe and water, there are some small farms with a main road cut through those farms. The red triangles in Figure 13 and Figure 14 indicate positions of the deposited rocks which were described as rock fall no 1 and no 2 in NGI report (Domaas, 1995).

In term of terrain surface types, the requirements are different by the two models.

RAMMS::Rockfall requires first an overall terrain material which cover the whole model domain, then users will identify other terrain material areas by inserting different shape areas into the model. RAMM::Rockfall introduces a set of friction parameters which connects to each terrain material type as presented in Table 4 on page 21 or the set of friction parameter can be defined by advance users. Figure 13 presents the terrain material areas that were defined for Holaviki as input in RAMMS::Rockfall. The areas which were not covered by any shape area will be have characteristic of overall terrain material.

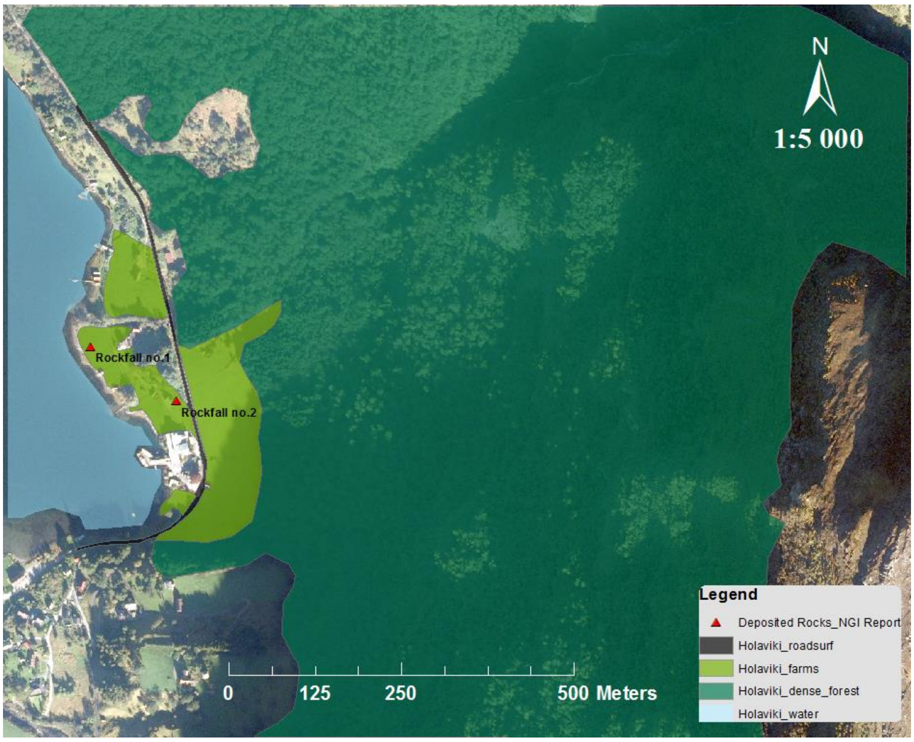


Figure 13: Holaviki terrain material map for RAMM::Rockfall

The soiltypes in Rockyfor3D relates to the normal coefficient of restitution value (Rn), and Rockyfor3D introduces 8 soiltypes (with ID from 0 -7) associate with 8 mean Rn values (see Table 5 on page 24). Figure 14 presents how the soil type areas were identified for Rockyfor3D

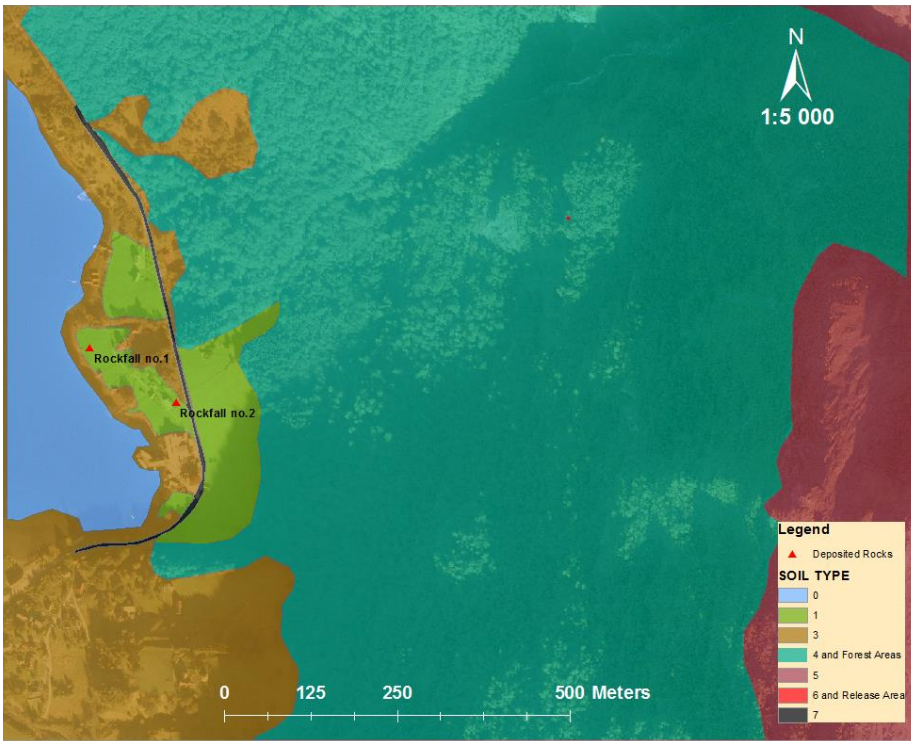


Figure 14: Holaviki soiltypes map for Rockyfor3D

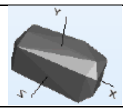
RAMMS::Rockfall classifies terrain material from extra soft to extra hard, as presented in Table 4 on page 21, which somehow is not easy for user to evaluate based on field survey pictures whether the terrain material is soft or hard without measuring. On another hand, Rockyfor3D has a library which shows examples for different slope surface types and suggests the associate parameters (soiltypes and surface roughness) for each kind of slope surface (Annexe II in (Dorren, 2012)), that helps users defining the terrain areas in an easier way.

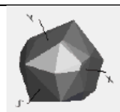
6.1.3. Holaviki – rock form library

RAMMS::Rockfall comprise a tool to build release rock, it is called Rock Builder. It is also possible for RAMMS::Rockfall's users to import a user-defined rock file into the model for example from laser scan data. Otherwise, there are 3 predefined rock shapes available in the Rock Builder application, which are Long, Equant and Flat shape. When rock shape, density and volume were identified by user, Rock Builder will come up with rock dimensions

Based on description of falling rocks in the NGI report (Domaas, 1995), which described a falling rock no 1 as a six-sided cross-section with sides between 1,5m and 3m and has a length of 5m and width of 3m, the average thickness is 1,5m and the volume was calculated to be 15m^3, a library of rocks was built using RAMMS::Rockfall Rock Builder. Table 7 shows rocks that will be employed in the model runs. All the rocks has rock density as 2700 (kg/m^3).

Table 7: Rock library for model testing by RAMM::Rockfall

Name	Shape	Dimensions X/Y/Z(m)	Mass (kg)	Volume (m3)	
Holaviki_ramms1	Long	4.29/2.15/2.15	40909.5	15.15	

Name	Shape	Dimensions X/Y/Z(m)	Mass (kg)	Volume (m3)	
Holaviki_ramms2	Equant	2.93/2.94/2.93	40851.4	15.13	
Holaviki_ramms3	Equant	2.42/2.19/2.05	17605.9	6.52	
Holaviki_ramms4	Flat	3.40/3.40/1.70	40982.2	15.18	

In rockfall trajectory simulation, RAMMS::Rockfall allows user to select either one rock from the library or the whole rock library as release rock(s) in the calculations.

In the case of Rockyfor3D, the rock's density, shape, dimension and volume are defined by using a set of raster data: rockdensity.asc, blshape.asc, d1/d2/d3.asc as described in 4.2. **Release rocks** on page 13.

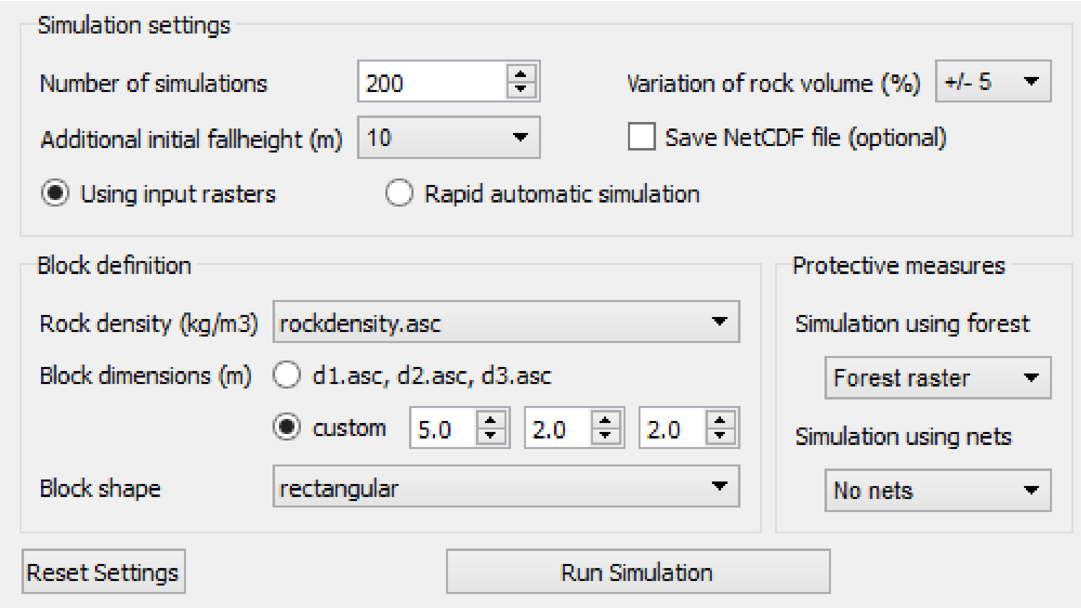


Figure 15: Simulation settings panel of Rockyfor3D

In the new version Rockyfor3D v5.2.1, the users can flexibly customise those parameters directly in the simulation setting (see Figure 15) without going back to make changes in the raster files. Depends on the defined shape and dimensions of the rock, Rockyfor3D will estimate the rock's volume.

Similar to as for RAMMS::Rockfall a library of rock with rock density is 2700 kg/m^3 was established to simulate the rockfall event in Holaviki (see Table 8).

Table 8: Rock library for model testing by Rockyfor3D

Name	Shape	Dimensions X/Y/Z(m)	Mass (kg)	Volume (m3)
Holaviki_rocky1	Rectangular	4.5/2.5/1.4	42525	15.750
Holaviki_rocky2	Ellipsoid	5.5/3.5/1.5	40821	15.119
Holaviki_rocky3	Sphere	3.1/3.1/3.1	42009	15.559
Holaviki_rocky4	Disc	5.0/3.0/2.0	42411	15.708
Holaviki_rocky5	Disc	3.0/2.0/2.0	16964	6.283

6.2. Model setup for back calculation analysis

The back calculations were done using RAMM::Rockfall Beta_1.6.23 and Rockyfor3D v5.2.1.

The NGI report (Domaas, 1995) described that the rockfall covered the scree on approximately 130 width (see Figure 16). A few single rocks kept bouncing and rolling as far as 310m beyond the talus toe (rockfall no1 and 2 in Figure 17). The details in the bouncing and rolling history of this rock are shown in Figure 25 on page 40.

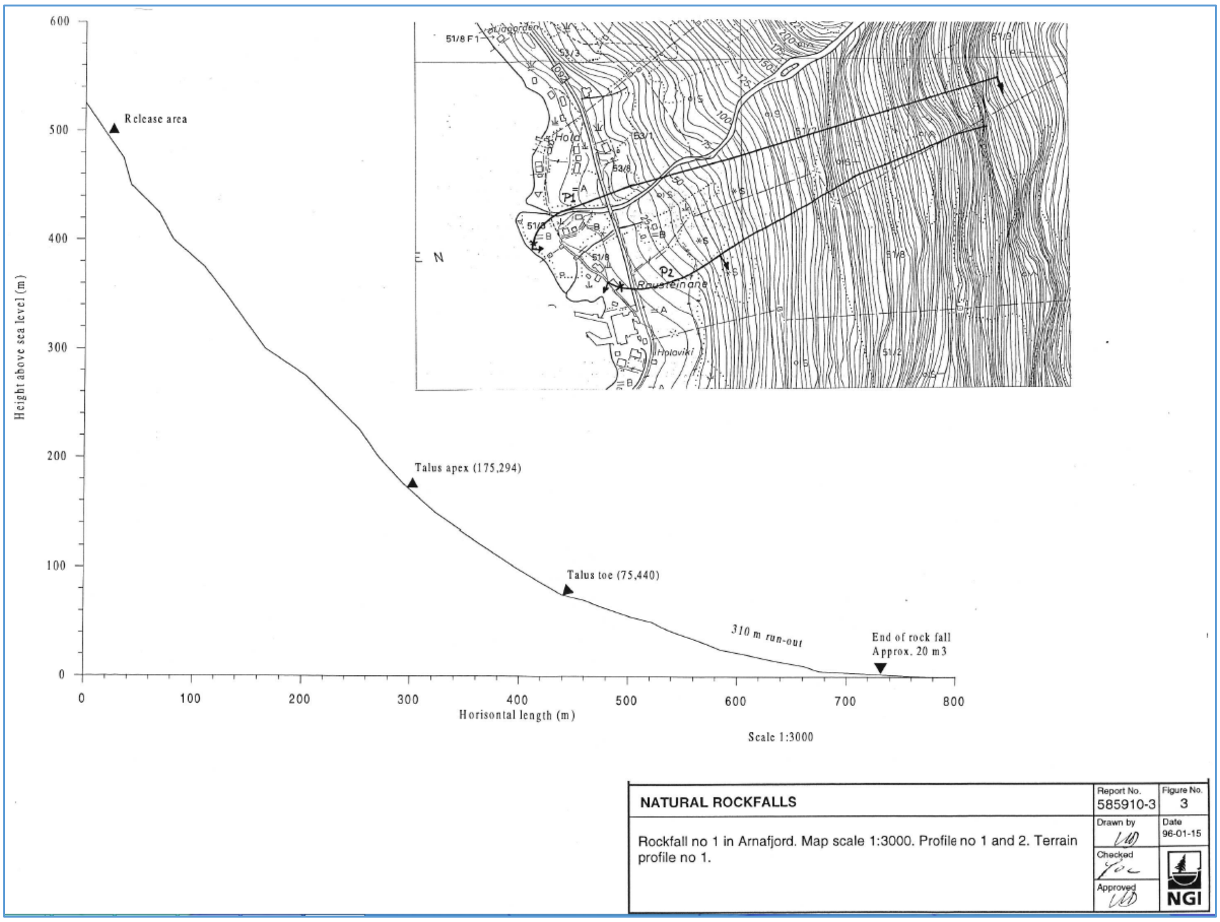


Figure 16: Rockfall in Arnafjord, Profile no 1, 2 (P1, P2) and terrain profile (source:(Domaas, 1995))

Figure 17:Photo of rockfall no1 (left) and rockfall no 2 (right) (source:(Domaas, 1995))

According to the report, the rockfall started at approximately 525m a.sl. and the talus toe ended at 75m a.sl. where most of the rockfall materials had come to rest. Based on information from the report, a release point was created with coordinates ReleasePoint(X, Y, Z) = (360981.54, 6766798.1, 492.73793), located in the area where the slope angle is between 60-70^o.

The red arrow in Figure 18 indicates the release point on the terrain slope.

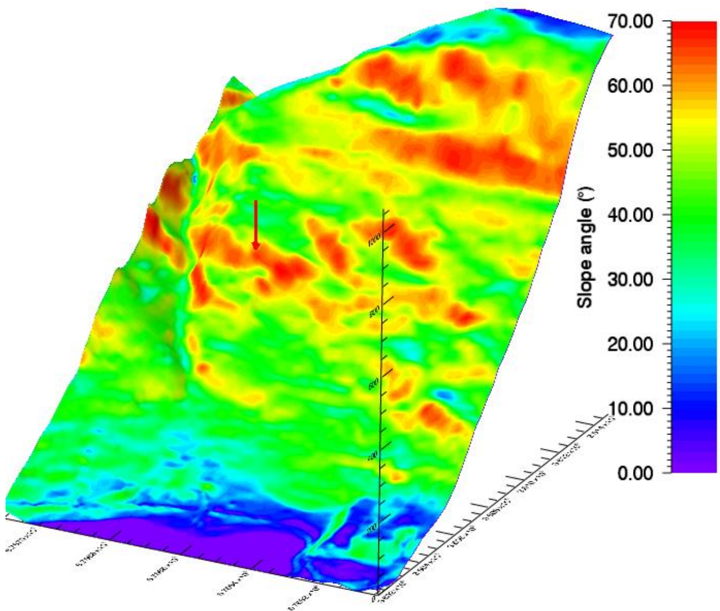


Figure 18: Release point on Holaviki slope

The goal of the back calculations is to reproduce the deposited rock positions of the rockfall event which was described in the NGI report (X_{event}; Y_{event}). From RAMMS::Rockfall and Rockyfor3D results, users can identify positions where there are highest number of deposited rock from the simulations (X_{siml}; Y_{siml}). The more deposited rocks that stopped close to the reference position the better the simulation results.

6.3. Rock trajectory back calculation analysis using RAMMS::Rockfall

The strategy that was applied in the back calculation was to include one parameter at a time to find the best parameter set for the simulation that could mimic the deposited rock position of the real rockfall event. For RAMMS::Rockfall, the best rock that fits the description of rockfall no. 1 (see Figure 17) in the NGI report is the Holaviki_ramms1 which has long shape and 15.2 m^3 as the volume (for rock's specification refer to Table 7 on page 29).

Table 9 presents scenario setting for the back calculations in RAMMS::Rockfall. All the scenarios used release type as "point" at NGI_ReleasePoint1(X, Y, Z) = (360981.54, 6766798.1, 492.73793) (see Figure 18). The Z-offset was set to be 10m and the number of rock random orientation was 200 (it means 1 rock for ex. Holaviki_ramms1 was rotated with a random angle before releasing it for 200 times). The water area (see Figure 13) was always included.

Table 9: Scenario setting for back calculations in RAMMS::Rockfall

RAMMS	Friction		Forest/Moor		Rocks
	Overall Terrain Material	Material Shapes	Forest	Moor	No. of rocks
RAMMS_Sce1	Hard	none	none	Water	Holaviki_ramms1
RAMMS_Sce2	Medium Hard	none	none	Water	Holaviki_ramms1
RAMMS_Sce3	Hard	Farms (medium) Road (hard)	none	Water	Holaviki_ramms1
RAMMS_Sce4	Hard	Farms (medium) Road (hard)	Light (5m/1000kg/s)	Water	Holaviki_ramms1
RAMMS_Sce5	Hard	Farms (medium) Road (hard)	Light (5m/1000kg/s)	Water	Holaviki_ramms3
RAMMS_Sce6	Hard	Farms (medium) Road (hard)	Dense (5m/2000kg/s)	Water	Holaviki_ramms3

- RAMMS_Sce1

In RAMMS_Sce1, Holaviki_ramms1 was employed and all other parameters were excluded except the overall terrain material was first tried as "hard" (refer to Table 4 on page 21 for what does "hard" means). The results from the RAMMS_Sce1 run was presented in Figure 19 which show the trajectories as fan shape with the width of the spreading was about 550m, some trajectories stopped at the toe of the talus and most of the trajectories stopped at the flat areas and in front of the water area border. The locations of the deposited rocks also spread out, and the maximum number of rock at same location is up to 3 for this run.

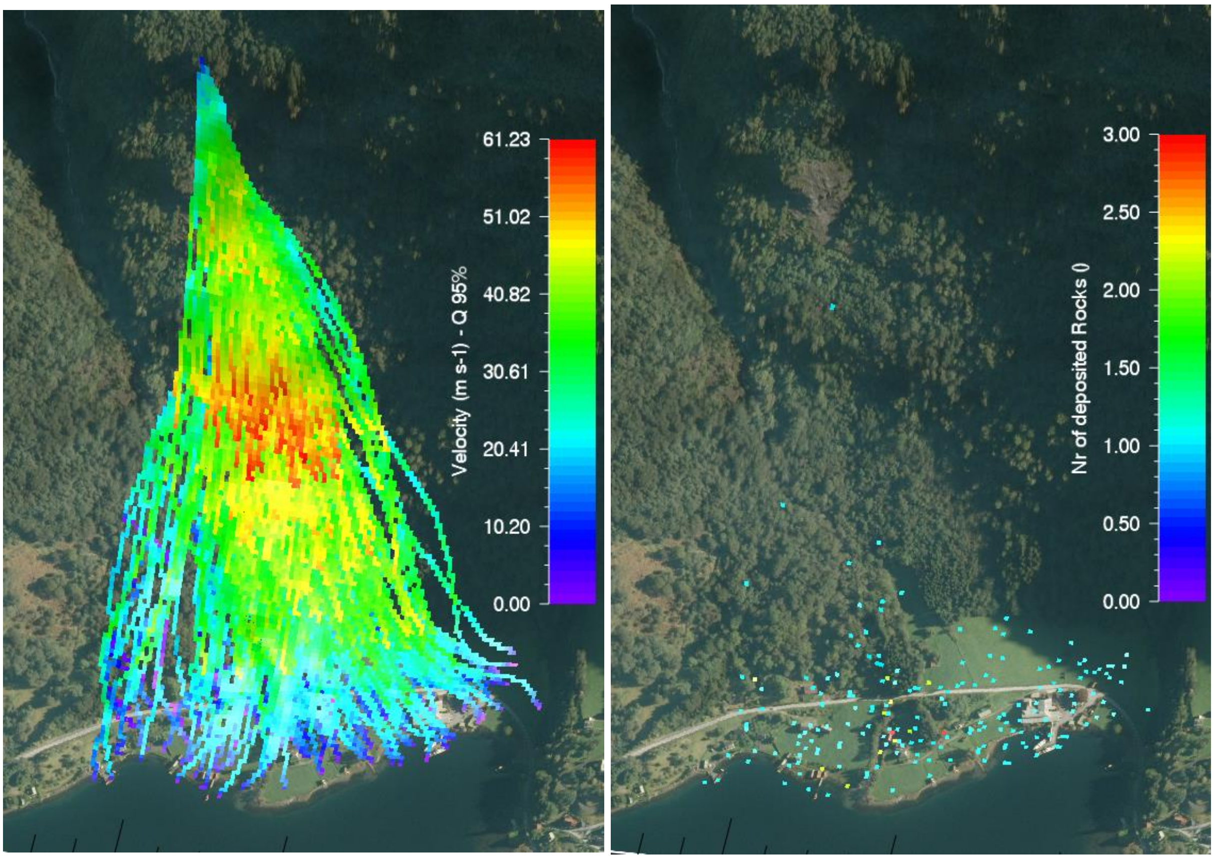


Figure 19: Trajectories plot and Deposited locations as results of RAMMS_Sce1

- <u>RAMMS_Sce2</u>

Assigning the overall terrain material as "hard" terrain for the model domain was question marked if it is suitable!? In the RAMMS_Sce2, the parameter setting was as same as RAMMS_Sce1, except the overall terrain material was changed from "hard" to "medium hard" (refer to Table 4 on page 21 for what does "medium hard" means).

The results from the RAMMS_Sce2 run show clearly the effect of the softer overall terrain material on the long shape and heavy rock (about 41 tons), about half a number of 200 rocks stopped along the slope, about another half landed at the flat area right after the end of the talus and no rock reached the water border.

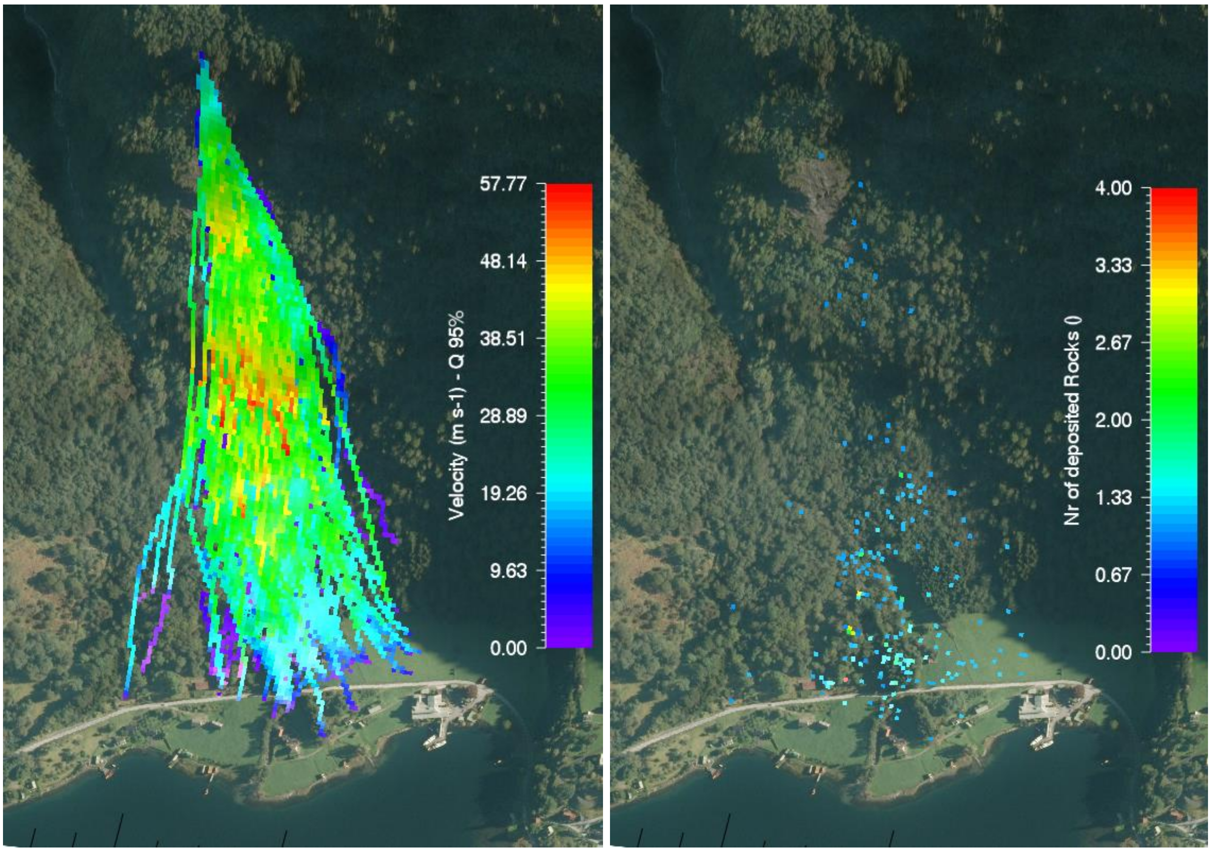


Figure 20: Trajectories plot and Deposited locations as results of RAMMS_Sce2

The conclusion after the two scenario runs was that the “hard” overall terrain material seem to be suitable for this area, but at the flat area at the end of the talus the terrain materials are definately not the same.

- <u>RAMMS_Sce3</u>

Based on the RAMMS_Sce1, farm and road surface areas were added in the RAMMS_Sce3 simulation with the terrain material as medium and hard, in order respectively.

Comparing the results from the RAMMS_Sce1 and RAMMS_Sce3 runs, one could see in general the trajectories stopped earlier, the general run-out zone is about 30-50 m shorter. In RAMMS_Sce3 result, there were less rocks that end up in the water compare to in RAMMS_Sce1. But the spreading areas of the deposited rocks in the two runs are similar both in scale and position (see Figure 21).

We can interpret that when the falling rocks reach the flat area at the end of the talus, and had to pass through the farm areas which are “medium” in the hardness scale, the kinetic energy of the falling rock was effected by the larger ground drag or larger friction in another word. The “medium” terrain material has ground drag as 0.6 while the “hard” terrain material has ground drag as 0.4.

The added road surface is quite narrow and almost perpendicularly crosses the main trajectory direction, so the effect was not clear but it was existing.

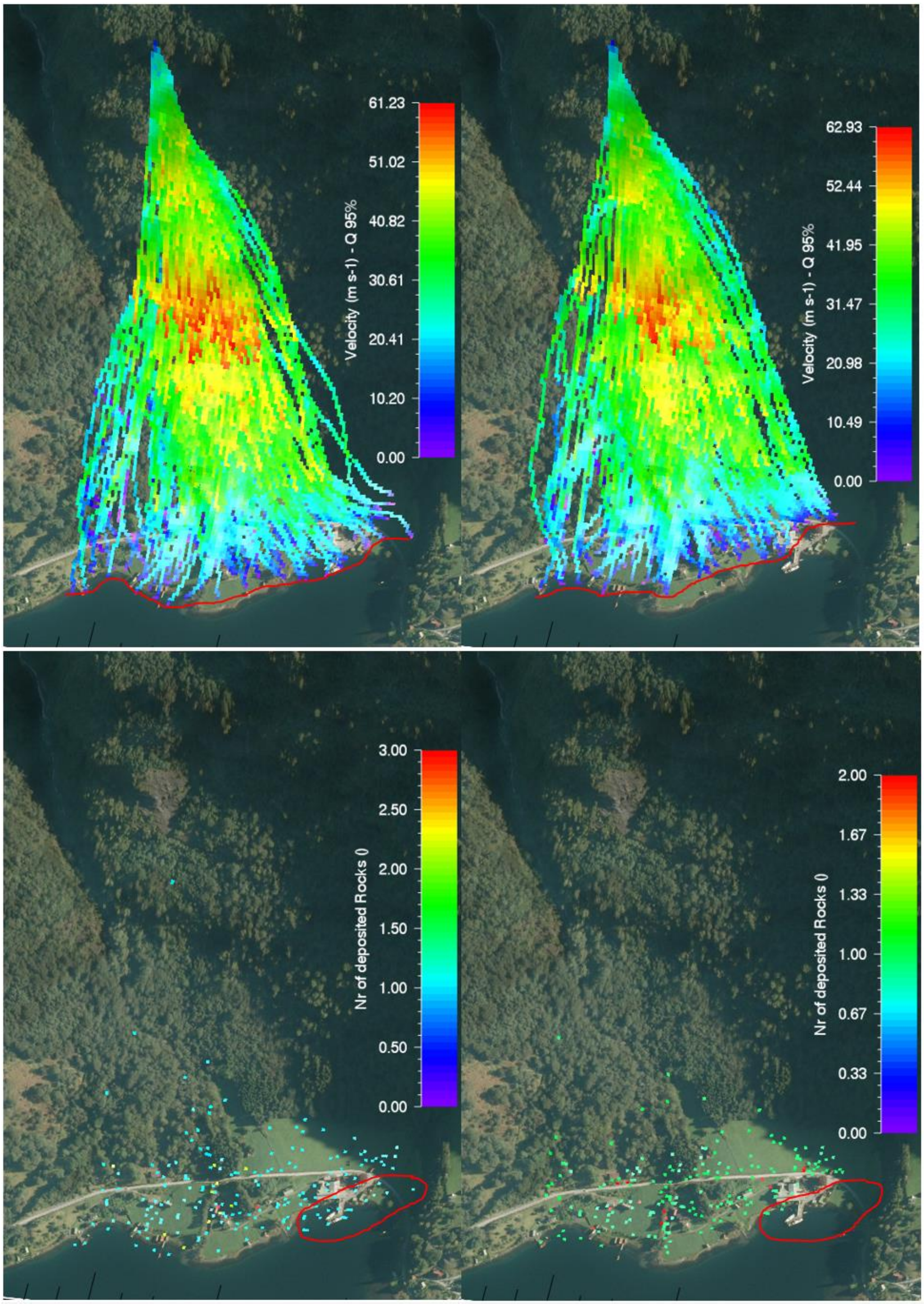


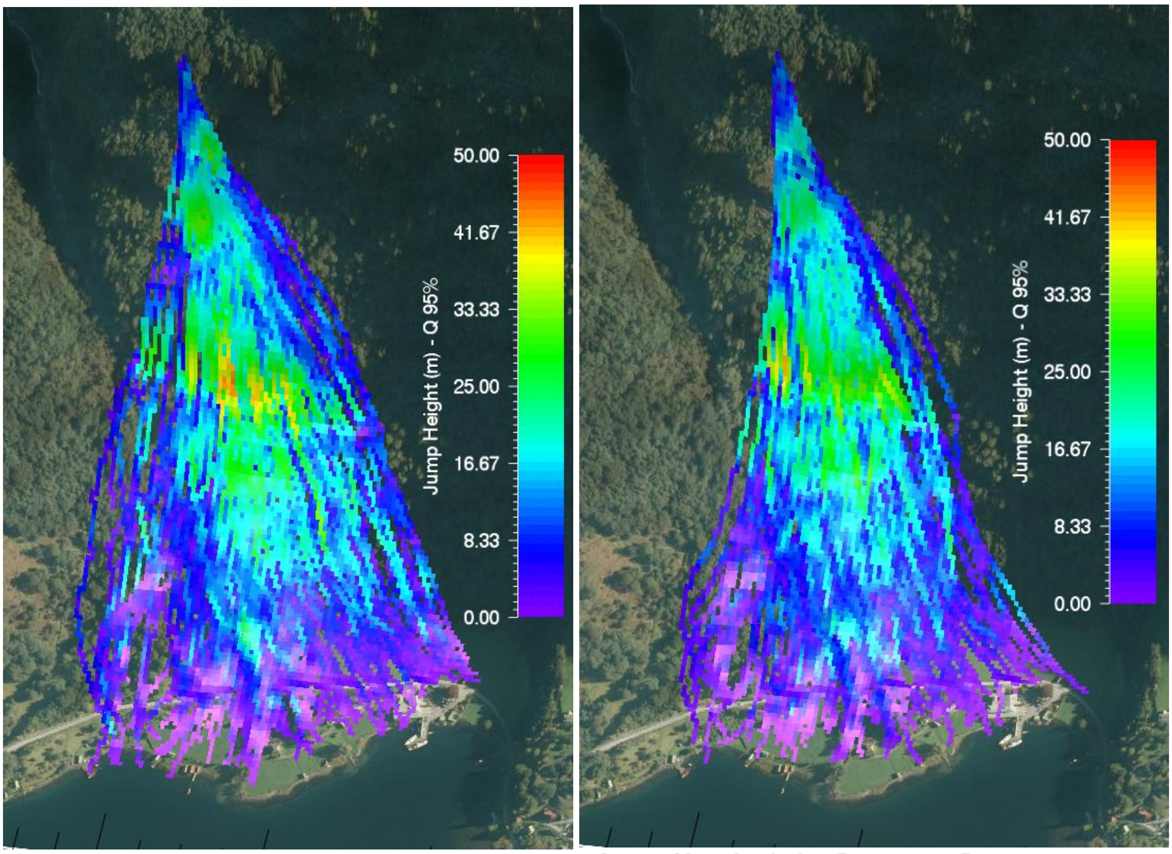
Figure 21: comparison trajectories and deposited positions between RAMMS_Sce1 (left-upper & lower) and RAMMS_Sce3 (right-upper & lower)

- <u>RAMMS_Sce4</u>

The slope at Holaviki from top to the toe of the talus was covered by forest. Therefore, forest areas as shown in Figure 13 was added into the simulation setting based on RAMMS_Sce3 to create RAMMS_Sce4. The forest layer was included as light forest in RAMMS_Sce4, with drag layer height at 5m and having forest drag of 1000 kg/s to best describe the forest in the Holaviki area.

The effect of adding the forest areas was similar to adding farm areas with higher ground drag. The drag forest reduce the run-out distance adding to the reduction by farm ground drag.

When looking at the jump height (see Figure 22), in the forest area, the resulting jump height in average was slightly decrease from mean jump height as 7.29m in RAMMS_Sce3 to mean jump height as 6.83 in RAMMS_Sce4. Regarding space distribution, over all forest areas the jump height decrease. That confirmed the forest drag which acted within the thickness of the forest layers, in this case was 5m, when the centre point of the falling rock was below the forest layer drag.



Jump Height (m) - Statistics Summary:
Parameter: Jump Height (m)
Min / Max: 0.64 / 44.98 — Nr of Data Values: 31202
Mean / Median: 7.29 / 5.27 — Histogram Bin Size: 0.43
Std Dev: 6.02
Q1 / Q3 / IQR: 2.94 / 9.81 / 6.87
Q90 / Q95 / Q99: 15.49 / 19.84 / 27.85

Jump Height (m) - Statistics Summary:
Parameter: Jump Height (m)
Min / Max: 0.85 / 41.90 — Nr of Data Values: 30239
Mean / Median: 6.83 / 5.02 — Histogram Bin Size: 0.39
Std Dev: 5.53
Q1 / Q3 / IQR: 2.85 / 9.01 / 6.16
Q90 / Q95 / Q99: 14.36 / 18.27 / 26.84

Figure 22: Jump height as results of RAMMS_Sce3 (left) and RAMMS_Sce4 (right)

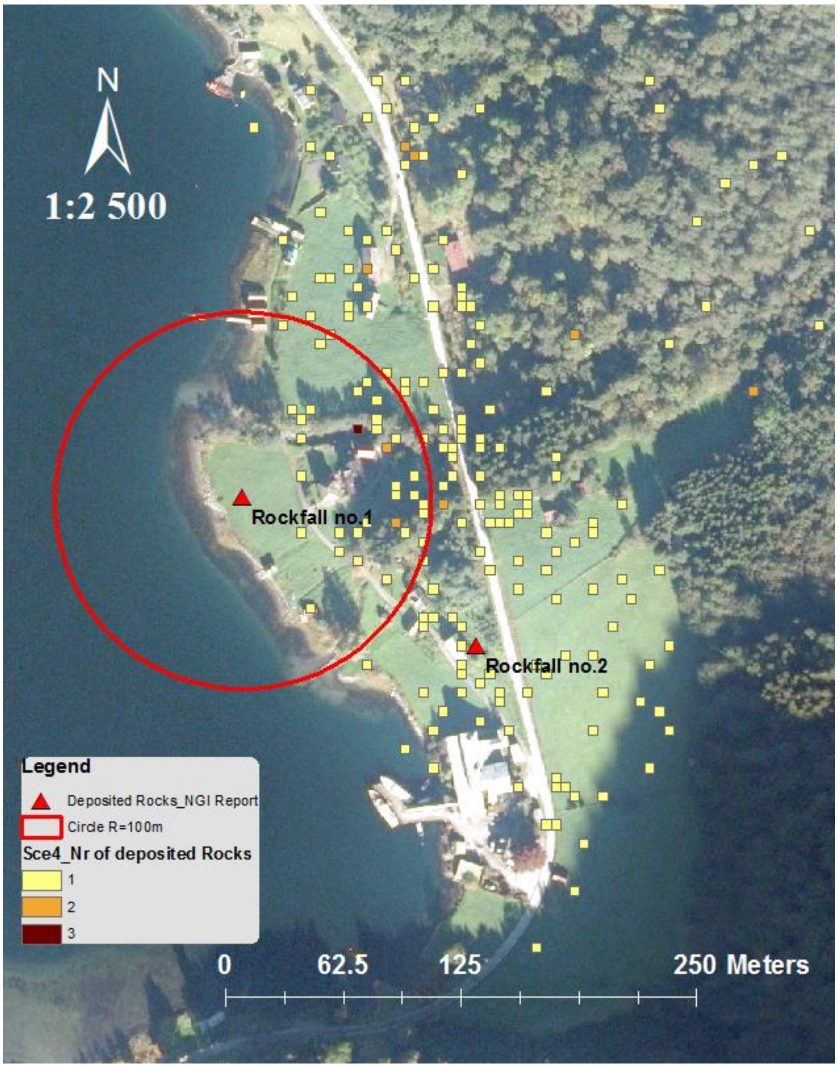


Figure 23: Position of RAMMS_Sce4 deposited rocks in relation to the NGI deposited rocks

When looking at the deposited position of the falling rocks from the RAMMS_Sce4 run, Figure 23 shows that there was still a distance gap from the locations where most of the simulated rocks deposited to where the NGI Rockfall no.1 was. The closet simulated rock, named Hola_Sce4_R33 (indicated by red arrow in Figure 23), was located at 29m away from the Rockfall no.1. The distance somehow agreed with what has been described in the NGI report "The calculation based on earlier experience on how far rockfall travels indicate a reach 30m shorter than this case" (Domaas, 1995). The Rockfall no.1 in the NGI report had travelled longer than the earlier observed ones.

In this back calculation analysis, the goal was scientifically simulate the rockfall event to get the results which show there were as many rocks close to the deposited rock from the NGI report (Rockfall no.1) as possible. Looking back to what had been reported in the NGI report that "the rockfall started at approximately 525m a.sl." while in the back calculations, the release point has coordinates NGI_ReleasePoint1(X, Y, Z) = (360981.54, 6766798.1, 492.73793), located in the area where the slope angle is between 60-70^{o}. There was about 32m gap in the altitude of the release rocks. Therefore in RAMMS_Sce4C, the Z-offset was increased to 32m with high expectations that the run-out distance would be increased.

- RAMMS_Sce4C

The rockfall simulation parameters setting for RAMMS_Sce4C was as same as RAMMS_Sce4 with the Z-offset was set to 32m instead of 10m in RAMMS_Sce4.

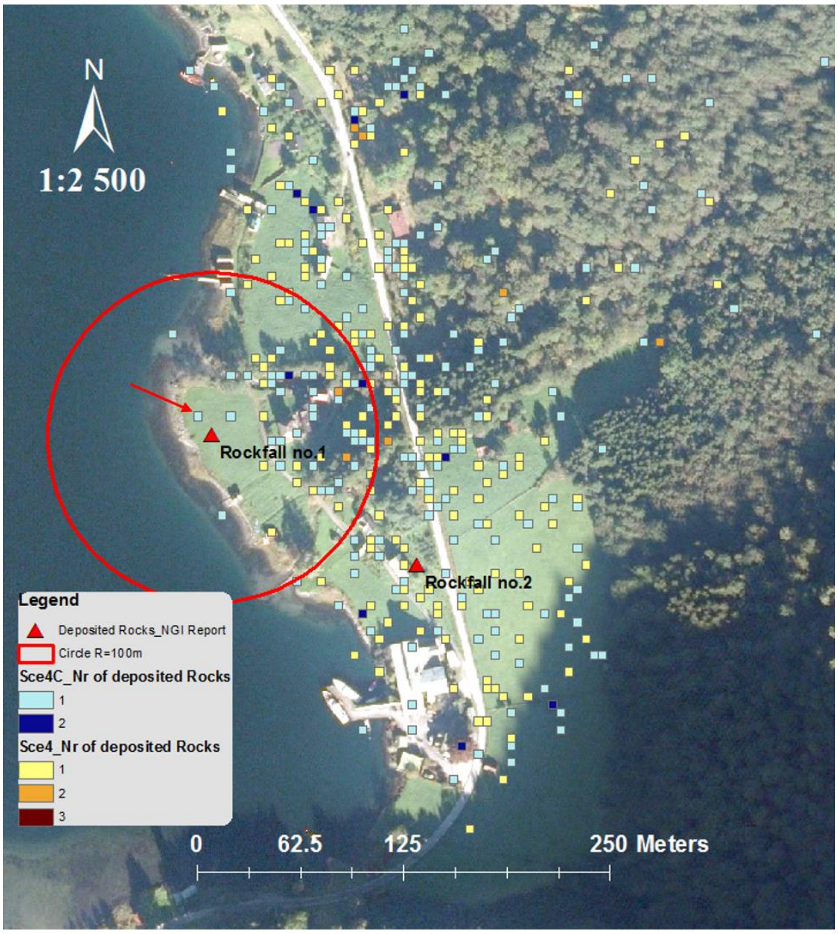


Figure 24: Position of deposited rocks from RAMMS_Sce4 vs. RAMMS_Sce4C

Within the 100m distance from the Rockfall no. 1 (red circle in Figure 24), there were 35 deposited rocks from the RAMMS_Sce4 run compare to 38 deposited rocks from the RAMMS_Sce4C run. Even though the number of deposited within the circle from the two runs has no significant increasing but the results from RAMMS_Sce4C's run indicate the increasing in general of the run-out distances for about 16m compare to the one from RAMMS_Sce4.

The rock named Hola_Sce4C_R93 (pointed by red arrow in Figure 24) is the one that deposited closest to the NGI rockfall no. 1. The distance between the two rocks is 12m. Studying the details in the bouncing and rolling of the two rocks is necessary in the back calculation analysis. It took 38.38 second from the starting point to where the rock Hola_Sce4C_R93 deposited.

According to the NGI report for Rockfall no. 1, the distance between the impact crater at Point O to the middle of the impact crater at Point A was 46m and the next jump last for 33 meters (see Figure 25). The bouncing data of the Hola_Sce4C_R93 shows two similar big jumps at approximately same altitude level and run-out distance, and rolling for the rest of the trajectory. Table 10 and Figure 25 show detail bouncing and rolling data of the two rocks. The detail values of each movement was recorded and shown in the Appendix.

Table 10: Detail bouncing and rolling history of falling rocks

Rock	Distance (m)		Height (m) (above sea level)			Max Jump height (m)		Velocity (m/s)			
	O→A	A→B	O	A	B	O→A	A→B	Starting at O	Incoming at A	Starting at A	Incoming at B
NGI Rockfall no.1	46	33	48	33	22	NA	NA	19.8	27.5	17.4	22.4
Hola_Sce4C_R93	72.8	55.9	36.8	17.8	7	10.38	7.13	28.9	34.6	24.6	29.03

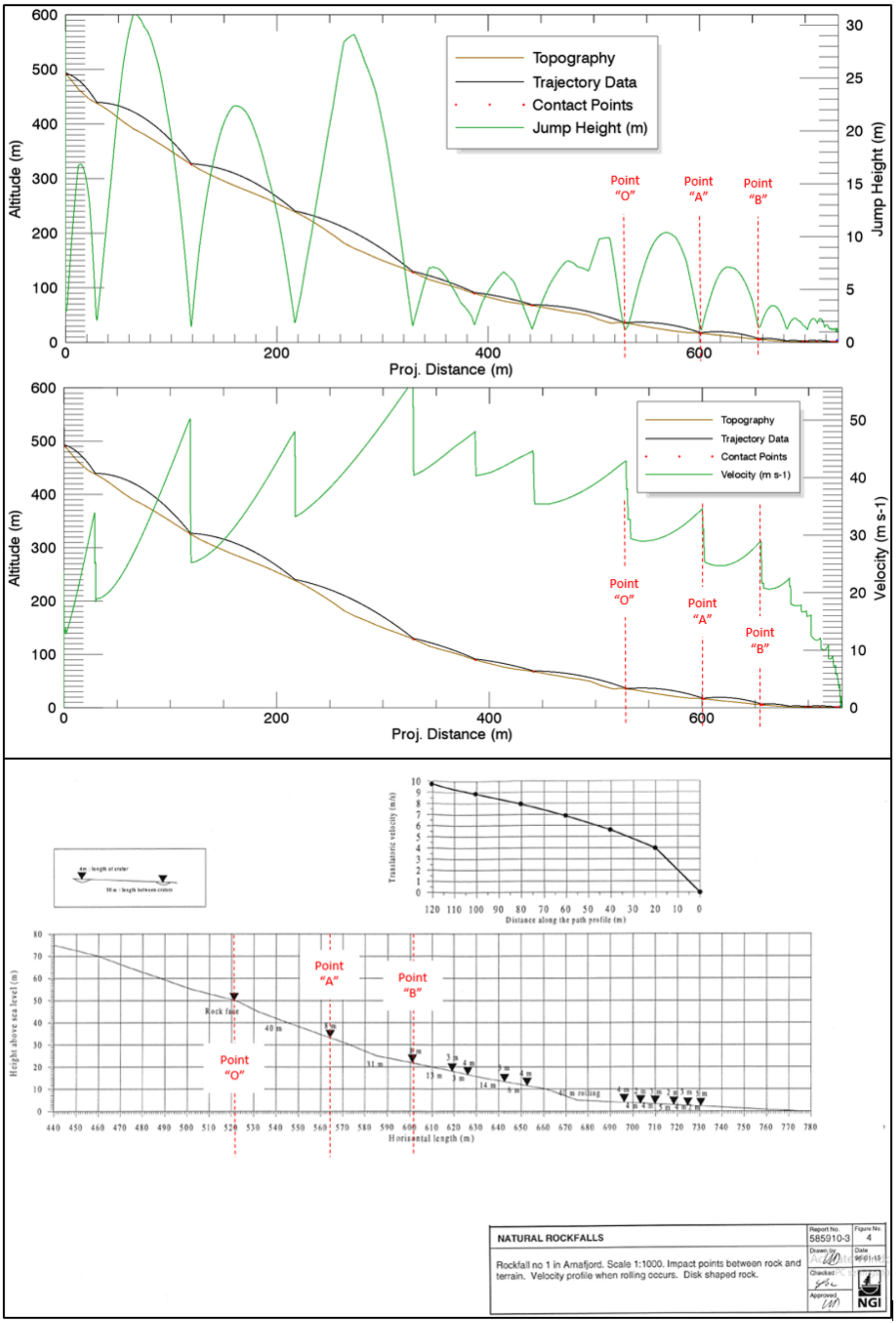


Figure 25: Detail bouncing and rolling history of Hola_Sce4C_R93 and Rockfall no. 1

- RAMMS_Sce5

The NGI report described Rockfall no 2 as a five sided rock with 1m thickness and sides of 3m, 1.5m, 2m, 2m, and 2m (volume: 6.5m^3). The best rock in the rock library in Table 7 that fits the description of rockfall no 2 is the rock named Holaviki_ramms3. It has equant shape with X/Y/Z dimensions as 2.42/2.19/2.05, weight 17606 kg and has volume as 6.52m^3.

In the RAMMS_Sce5, the simulation setting was based on the RAMMS_Sce4 with all the terrain parameters that were tested to be the most suitable one for the area, but using the Holaviki_ramms3 as the release rock. And the release point location was changed to NGI_ReleasePoint2(X, Y, Z) = (360955.14, 6766731.5, 408.74058) to represent the release location was described in the NGI report (see Figure 16 on page 31).

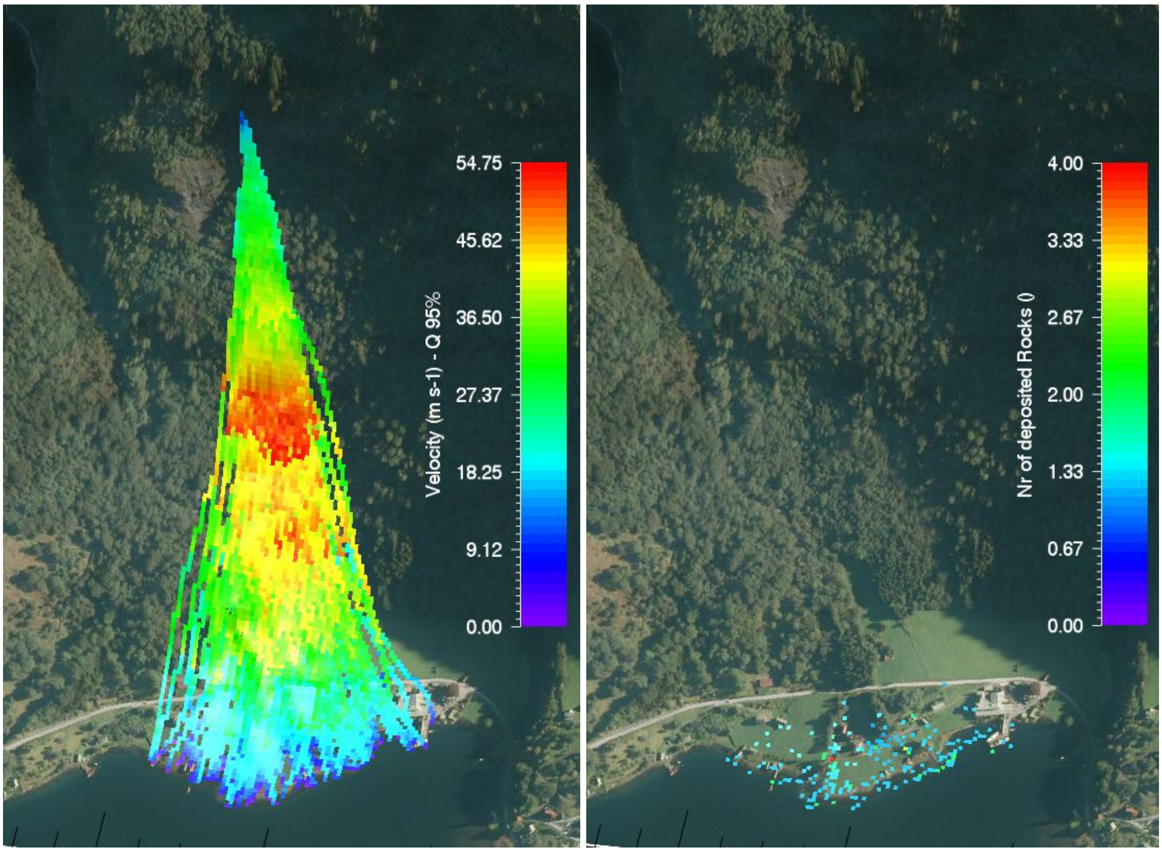


Figure 26: Trajectories plot and Deposited locations as results of RAMMS_Sce5

By changing the shape of the release rock only, it was not possible find good relation in rock deposition locations from the simulation run in RAMMS_Sce5 compare to the Rockfall no. 2 from the NGI report. Even though the rock volume was reduced about 2 times from 15.2m^3 to 6.52m^3, the shape of the release rock was the main reason that mattered the run-out distance. Hola_ramms3 rock has equant shape, compare to the long shape of the previously simulated rock. Many RAMMS_Sce5 simulated rocks landed on water areas, while the Rockfall no.2 in NGI report was deposited even further inland than the Rockfall no.1.

The possible reason could be that the Rockfall no.2 had encountered more frictions on its track, for example running through denser forest, softer terrain materials or hitting a damn as confirmed by NGI report.

- RAMMS_Sce6

For RAMMS_Sce6 run, the parameter setting was based on the RAMMS_Sce5, and the light forest was replaced by dense forest which has drag layer height at 5m and forest drag of 2500kg/s.

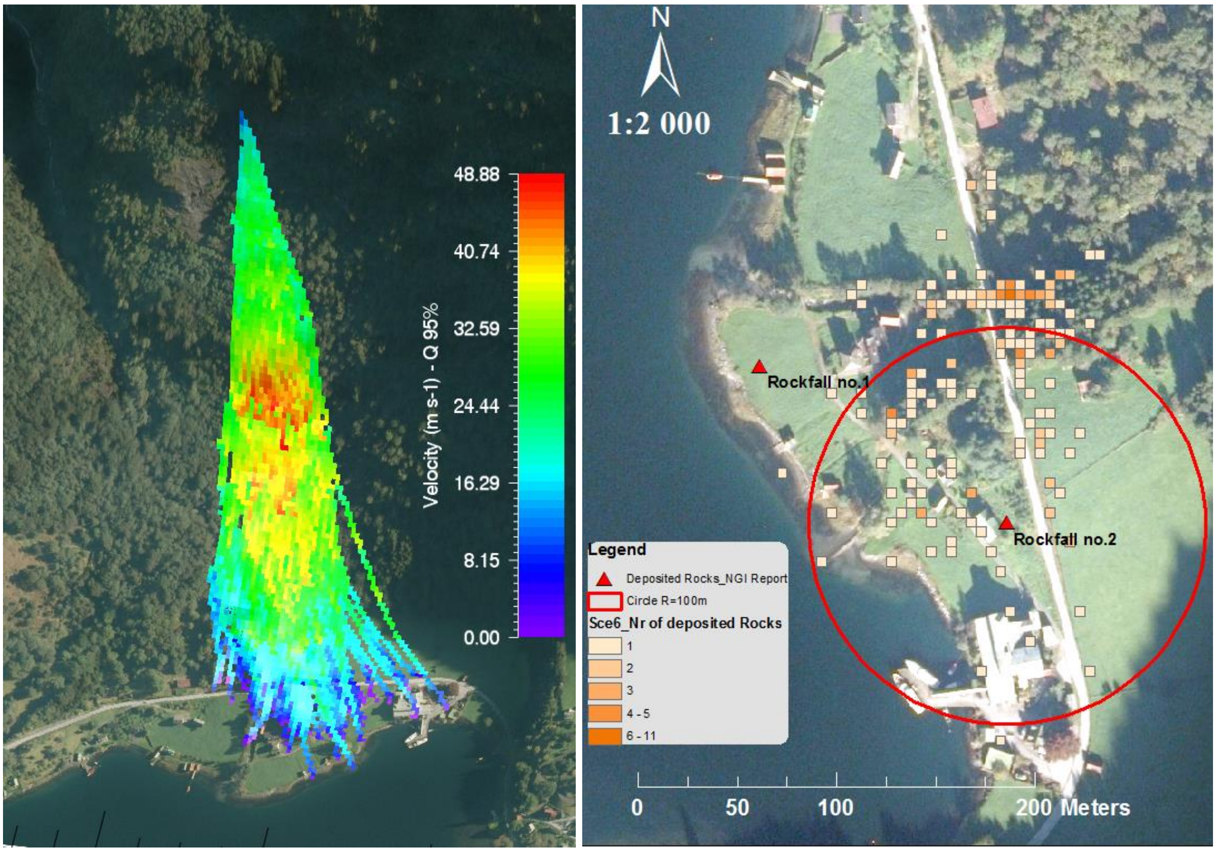


Figure 27: Rockfall trajectory and location of deposited rocks from RAMMS_Sce6 simulation

One could observe from Figure 27 that the run-out dispersion of RAMMS_Sce6 simulation was much narrower than the run-out dispersion of the previous scenarios, when the rock with long shape was employed. There are 103 rocks which deposited within 100m of rockfall no.2, more than ½ of the total 200 simulated rocks. Another half the number of rocks was landed centrally at small area just outside of the 100m radius circle, and the maximum number of deposited rocks at the same location is up to 11 rocks.

- Conclusion for back calculation analysis using RAMMS::Rockfall

Because of the randomly rotating of Initial Rock Orientation before release, it was impossible to reproduce exactly same results with the exactly same scenario setting, therefore the number of simulation rocks need to be high enough to be able to find the highest possibility based on statistical numbers. Thus, the 100m radius circle was used as a measurement area.

Simulation scenarios when all other parameters was exactly the same but only the rock shape was changed from long to equant shape had proved that rock shape was a clear factor that influence the run-out distance.

In the calculation of impact against tree, RAMMS::Rockfall only considers forest as a homogenously distributed friction layer which acts as linearly proportional to the rock velocity (but in the opposite direction). Therefore, the forest drag acted equally on all the rock trajectories, which is not always the true. Thus, there was a need in changing forest parameter setting for the back calculation analysis for Rockfall no.1 and Rockfall no.2 to take into account the randomly of meeting obstacles along the rockfall tracks.

6.4. Rock trajectory back calculation analysis using Rockyfor3D

In general the simulation approach of Rockyfor3D is in the same direction with RAMMS::Rockfall, but the format of the requirement input data has some differences as presented in Chapter 4 - Input data requirements - RAMMS::Rockfall versus Rockyfor3D on page 12. The three main differences are about rock form specification, terrain surface roughness and the forest specifications.

Even though there were differences in the input data, the experiences learnt from the back calculation analysis done by RAMMS::Rockfall was still very helpful in setting up testing scenarios in Rockyfor3D. The soiltypes of difference terrain areas were selected for Rf3D_Sce1 was based on landuse purposes and such experiences. At first the surface roughness setting was based on Rockyfor3D suggestions in *(Dorren, 2012) – Annexe II. Examples of parameter values for different slope surface types.*

Table 11 presents scenario setting for the back calculations in Rockyfor3D. All the scenarios used release cell as equivalent to NGI_ReleasePoint1(X, Y, Z) = (360981.54, 6766798.1, 492.73793) (see Figure 18). The Z-offset was set to be 10m and the number of simulated rock was 200 by changing the rock volume randomly within +/-5% by changing the rock's initial three dimensions. The water area (see Figure 14) was always included.

For Rockyfor3D, the best rock that fits the description of rockfall no. 1 (see Figure 17) in the NGI report is the Holaviki_rocky4 which has disc shape and 15.708m^3 as the volume (for rock's specification refer to Table 8 on page 30). Rock density was always set as 2700 kg/m^3.

Table 11: Scenario setting for back calculations in Rockyfor3D

	Rock	RG70	RG20	RG10	nrtrees	dbhmean	dbhstd	Conif _perc	SOILTYPE/Landuse
Rf3D_Sce1	Holaviki_rocky4	100	100	100	-	-	-	-	0 / Water
		0	0	0	-	-	-	-	1 / Farms
		0.03	0.05	0.05	-	-	-	-	2 / Residential
		0.05	0.1	0.2	0	0	0	0	3 / Forest Areas
		0	0.05	0.1	-	-	-	-	5 / Bedrock, thin soil cover
		0	0	0	-	-	-	-	6 / Release Area
		0	0	0	-	-	-	-	7/ Asphalt road
Rf3D_Sce2	Holaviki_rocky4	100	100	100	-	-	-	-	0 / Water
		0	0	0	-	-	-	-	1 / Farms
		0.03	0.05	0.05	-	-	-	-	3 / Residential
		0.05	0.1	0.2	2000	30	5	80	4 / Forest Areas
		0	0.05	0.1	-	-	-	-	5 / Bedrock, thin soil cover
		0	0	0	-	-	-	-	6 / Release Area

	Rock	RG70	RG20	RG10	nrtrees	dbhmean	dbhstd	Conif _perc	SOILTYPE/Landuse
		0	0	0	-	-	-	-	7/ Asphalt road
		100	100	100	-	-	-	-	0 / Water
		0	0	0	-	-	-	-	1 / Farms
		0.03	0.05	0.05	-	-	-	-	2 / Residential
Rf3D_Sce3	Holaviki_rocky5	0.05	0.1	0.2	2000	30	5	80	3 / Forest Areas
		0	0.05	0.1	-	-	-	-	5 / Bedrock, thin soil cover
		0	0	0	-	-	-	-	6 / Release Area
		0	0	0	-	-	-	-	7/ Asphalt road

- Rf3D_Sce2 vs. Rf3D_Sce1

The main difference between the two scenarios Rf3D_Sce1 and Rf3D_Sce2 was the increasing the “nrtrees” represent the number of stems per hectare within each cell from 0 to 2000.

The significant difference in the results of the two scenario runs was the shape of the run-out trajectories within the forest area on the slope. It is narrower at the upper part within the forest area. At the toe of the talus, the spreading areas are similar. It was clear that the forest had limited the spreading of the rock tracks (see Figure 28).

Table 12 presents the maximum energy value recorded (E_95CI), maximum passing height (Ph_95CI) and maximum velocity (V_max) as output from Rf3D_Sce1 and Rf3D_Sce2 simulations. Forest had a clear impact on reducing falling rock’s energy, jump height and velocity.

Table 12: Rockyfor3D output for Rf3D_Sce1 and Rf3D_Sce2 simulations

	E_95CI (KJ)	Ph_95CI (m)	V_max (m/s)
Rf3D_Sce1	88012	35.2	51.05
Rf3D_Sce2	74911.2	33.41	46.13

In both scenario simulations, there were higher jumps at the ending part of the trajectories where the terrain is flat, that is difference from what had been observed in all of the RAMMS::Rockfall simulations, where the high jumps happened on the upper part on the slope and rolling at the ending part of the rock trajectories. (see Figure 22 on page 37)

With Rockyfor3D, even though difference soiltype had been tested and selected carefully to account the possibly real soiltype in the Holaviki area, but the run-out distance in all the simulation runs were still longer than in RAMMS::Rockfall simulations. And more rock had reached the water than in RMMS::Rockfall simulations.

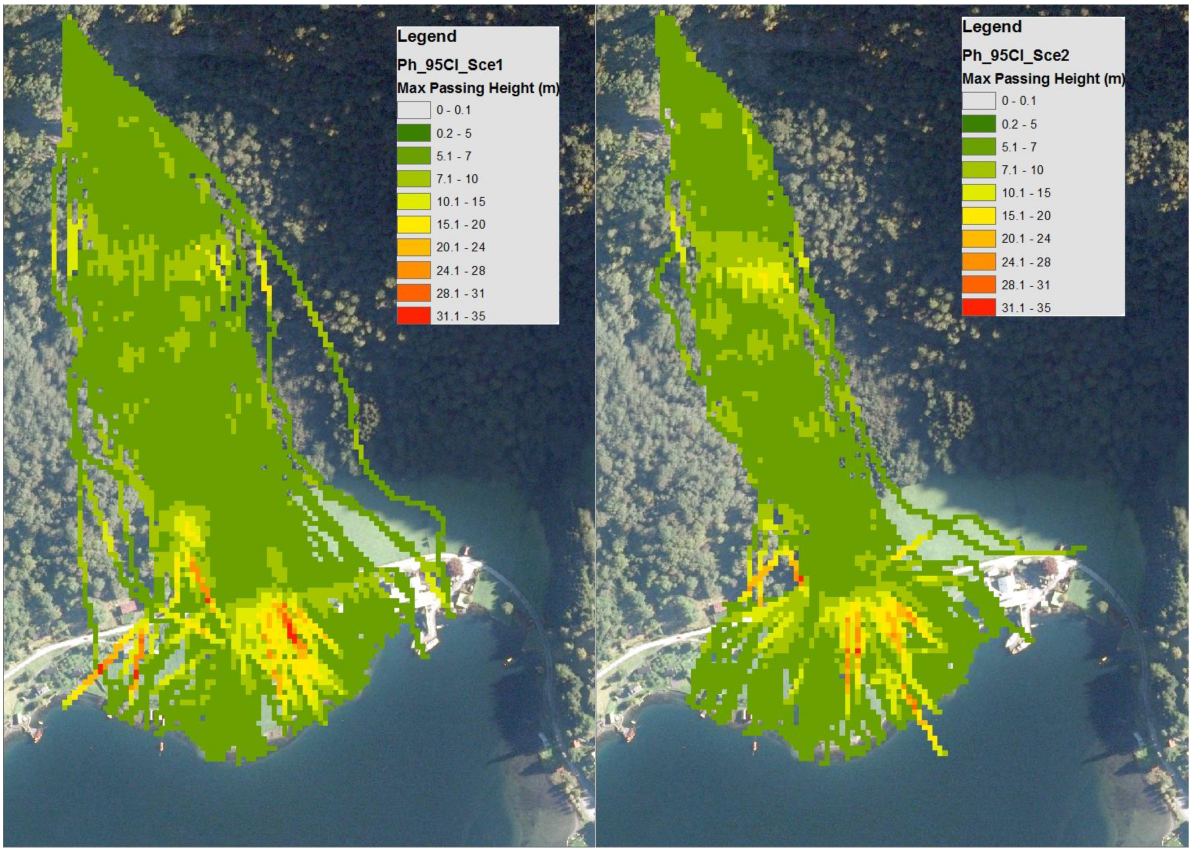


Figure 28: Trajectories plot as results of Rf3D_Sce1 (left) and Rf3D_Sce2 (right)

Therefore, when looking at the deposited locations, similar to what had been employed in RAMMS::Rockfall simulation, a 100m radius circle was used calculate the number of deposited rock landed within 100m from the NGI deposited rock. But in additional, all the deposited rocks within water area had been taken out of the sum calculation. The remaining rocks within 100m of NGI_Rockfall no.1 was 79 rocks for Rf3D_Sce1 and 94 rocks for Rf3D_Sce2 simulation (see Figure 29).

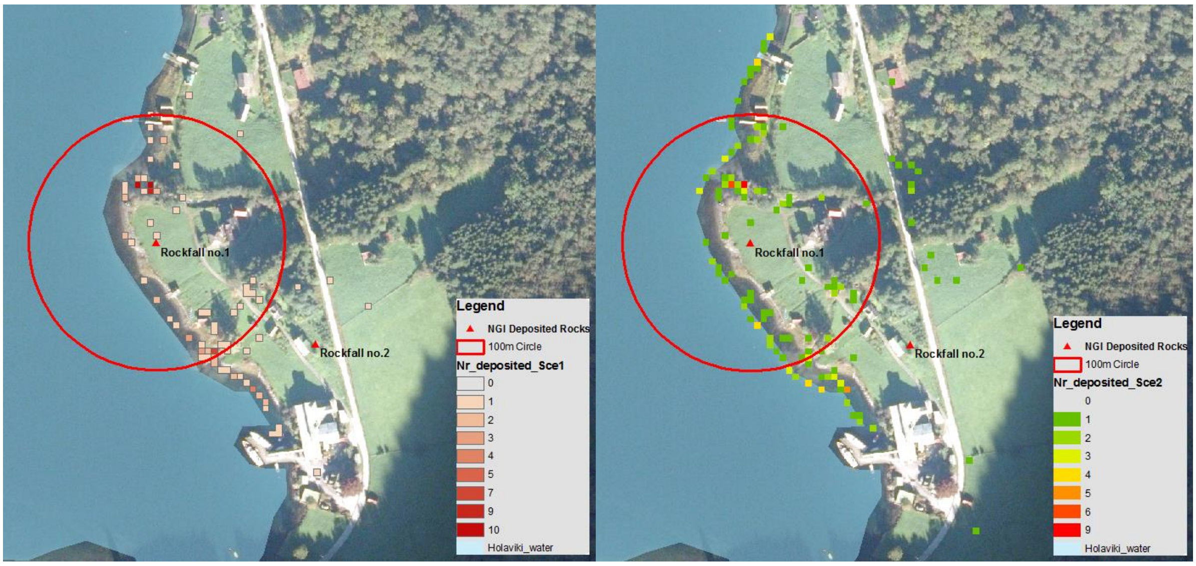


Figure 29: Deposited locations as results of Rf3D_Sce1 (left) and Rf3D_Sce2(right)

- Rf3D_Sce3

The back analysis calculation for the NGI_Rockfall no.2 was implemented in the Rf3D_Sce3, where the parameter setting was based exactly on Rf3D_Sce2, but replace the falling rock by Holaviki_rocky5 which has 3.0/2.0/2.0 for X/Y/Z dimensions and disc shape, rock volume 6.283m^3, rock mass 16964.1 kg. The release point at NGI_ReleasePoint2(X, Y, Z) = (360955.14, 6766731.5, 408.74058).

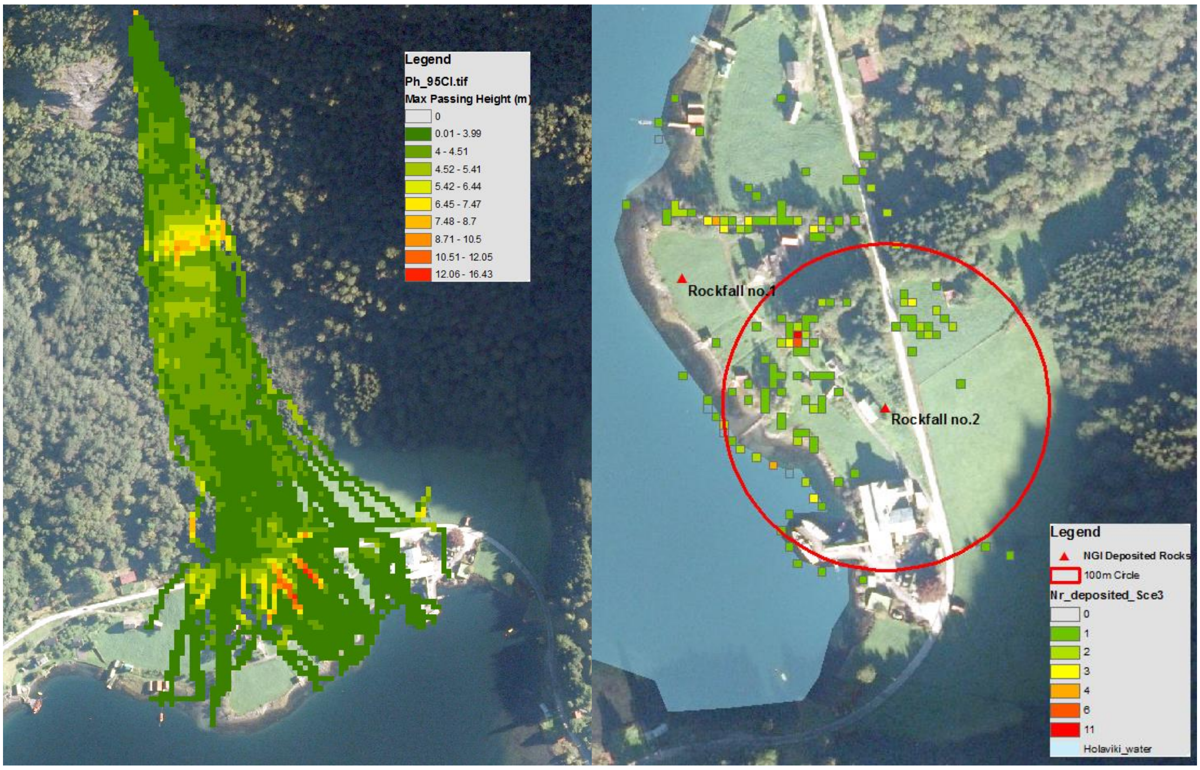


Figure 30: Trajectories (left) and deposited location (right) as results of Rf3D_Sce3

Rf3D_Sce3 simulation results for NGI_Rockfall no.2 were presented in Figure 30. From the release point at lower latitude (408m) and smaller rock volume (6.283m^3), the run-out distance is shorter in this case and more rock deposited on land. Within 100m radius circle from the NGI_Rockfall no.2 there were 96 rocks that landed within the area.

- <u>Conclusion for back calculation analysis using Rockyfor3D</u>

It is not clear how Rockyfor3D randomly change the rock volume within +/-5% by changing the rock's initial three dimensions. The testing showed that for the scenario where there is no forest and there is no change in the parameter setting of each simulation run, the result of those simulation runs are identical.

The passing height were higher the ending part of the trajectories where the terrain is flat, especially the simulated rocks jumped higher after the road surface border. This need to be studied more in detail, whether hitting the hard surface, even though the road surface is just a narrow line crossing the rock trajectories, made the rocks jumped like hitting a small dike.

6.5. RAMMS::Rockfall vs. Rockyfor3D

Through the results from the theory studies and the back analysis calculations by each model individually mode, a comparison can be made. The three main differences between RAMMS::Rockfall and Rockyfor3D have been identified, which are:

- The matter of rock forms
- The rock run-out distance
- The impact of forest

The back analysis calculations helped to identify the parameter setting that best suitable to use in the two models that were applied on the same study, Holaviki.

6.5.1. The matter of rock forms and run-out distance

Simulation runs with different rock forms were carried out to assess the matter of rock forms in the two models, RAMMS::Rockfall and Rockyfor3D

6.5.1.1. The matter of rock forms and run-out distance in Rockyfor3D

Table 13 presents some main output parameters from the simulation with difference rock forms were done using Rockyfor3D. The ellipsoid rocks moved down fastest and have highest energy than the others, they also jumped higher (see Figure 31), and the maximum passing height in the whole model domain for ellipsoid rocks was 43.64m in average the jump height was 8.67, highest compare to other rock forms. The spherical rock had lowest energy, mostly rolling on the flat area, the spherical rock trajectories were almost straight down the slope and concentrated in a narrow area.

For all the rock forms, the high jumps happened mainly at the end of the talus, the ellipsoid forms highest passing height (43.64m) appeared at the ending part of the trajectories after the crossing main road (see Figure 32).

The ellipsoid rocks also had accumulated highest energy along the falling tracks. The max_E95CI of ellipsoid was 87372.2 KJ (which jumped highest) compare to 67832.1 KJ of the spherical rocks (which jumped less).

Table 13: Parameters as outputs of Rockyfor3D for difference rock forms simulations

Rock name	Shape	Max/Mean E_95CI (KJ)	Max/Mean Ph_95CI (m)	Max/Mean V_max (m/s)
Holaviki_rocky2	**Ellipsoid**	87372.2/47951.33	43.64/8.67	47.64/34.92
Holaviki_rocky4	**Disc**	74911.2/43478.39	33.41/7.50	46.13/32.95
Holaviki_rocky1	**Rectangular**	78936.5/38726.92	27.14/6.30	47.58/31.57
Holaviki_rocky3	**Sphere**	67832.1/30908.44	18.78/5.64	45.44/31.02

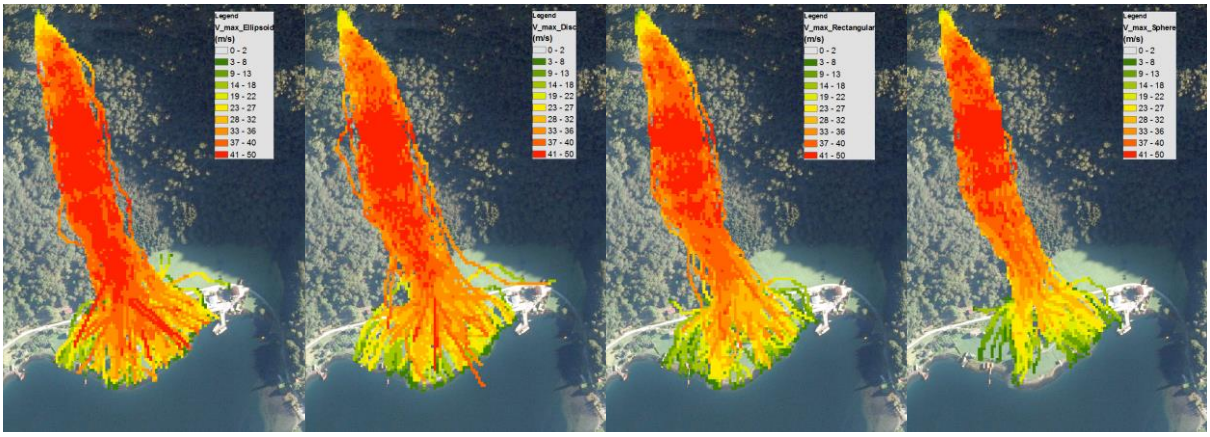


Figure 31: Max velocity by difference rock forms in Rockyfor3D. Ellipsoid (left), Disc (middle-left), Rectangular (middle-right), Sphere (right)

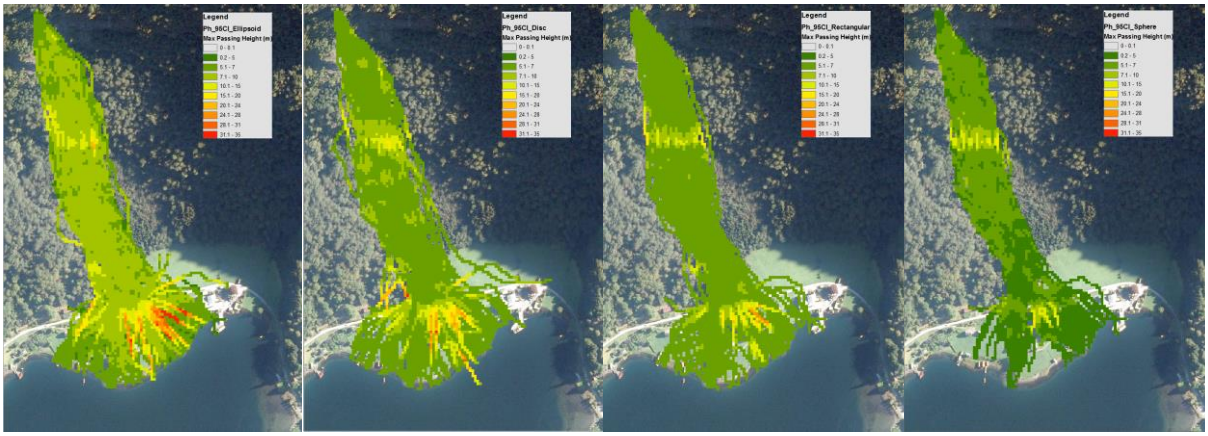


Figure 32: Max Passing Height by difference rock forms in Rockyfor3D. Ellipsoid (left), Disc (middle-left), Rectangular (middle-right), Sphere (right)

With the fact that the spherical rocks jumped less, had less energy and rolling more at the end of the slope compare to the others, they stopped earlier than the others. The run-out distances of the spherical rocks were shorter then run-out distance of other rock forms by Rockyfor3D (see Figure 33).

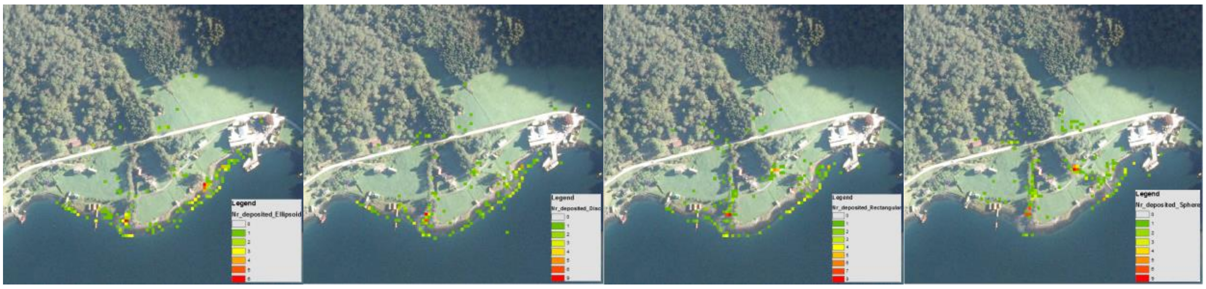


Figure 33: Deposited locations by difference rock forms in Rockyfor3D. Ellipsoid (left), Disc (middle-left), Rectangular (middle-right), Sphere (right)

6.5.1.2. The matter of rock forms and run-out distance in RAMMS::Rockfall

RAMMS::Rockfall introduces 3 main rock forms: Long, Equant and Flat. The rocks, with volume, mass and dimensions, built for the runs were presented in Table 7 on page 29.

Those three rock forms were employed in the simulation with the terrain and forest parameters setting as in RAMMS_Sce4 (see the scenario setting in Table 9 on page 33).

Table 14: Parameters as outputs of RAMMS::Rockfall for difference rock forms simulations

Rock name	**Shape**	**Max/Mean Energy (KJ)**	**Max/Mean Jump height (m)**	**Max/Mean Velocity (m/s)**
Holaviki_ramms2	**Equant**	102741.4/35490.7	67.69/9.37	68.16/35.13
Holaviki_ramms4	**Flat**	101374.2/23440.61	64.20/8.81	67.34/29.19
Holaviki_ramms1	**Long**	86295.2/22961.2	54.96/7.49	62.27/28.58

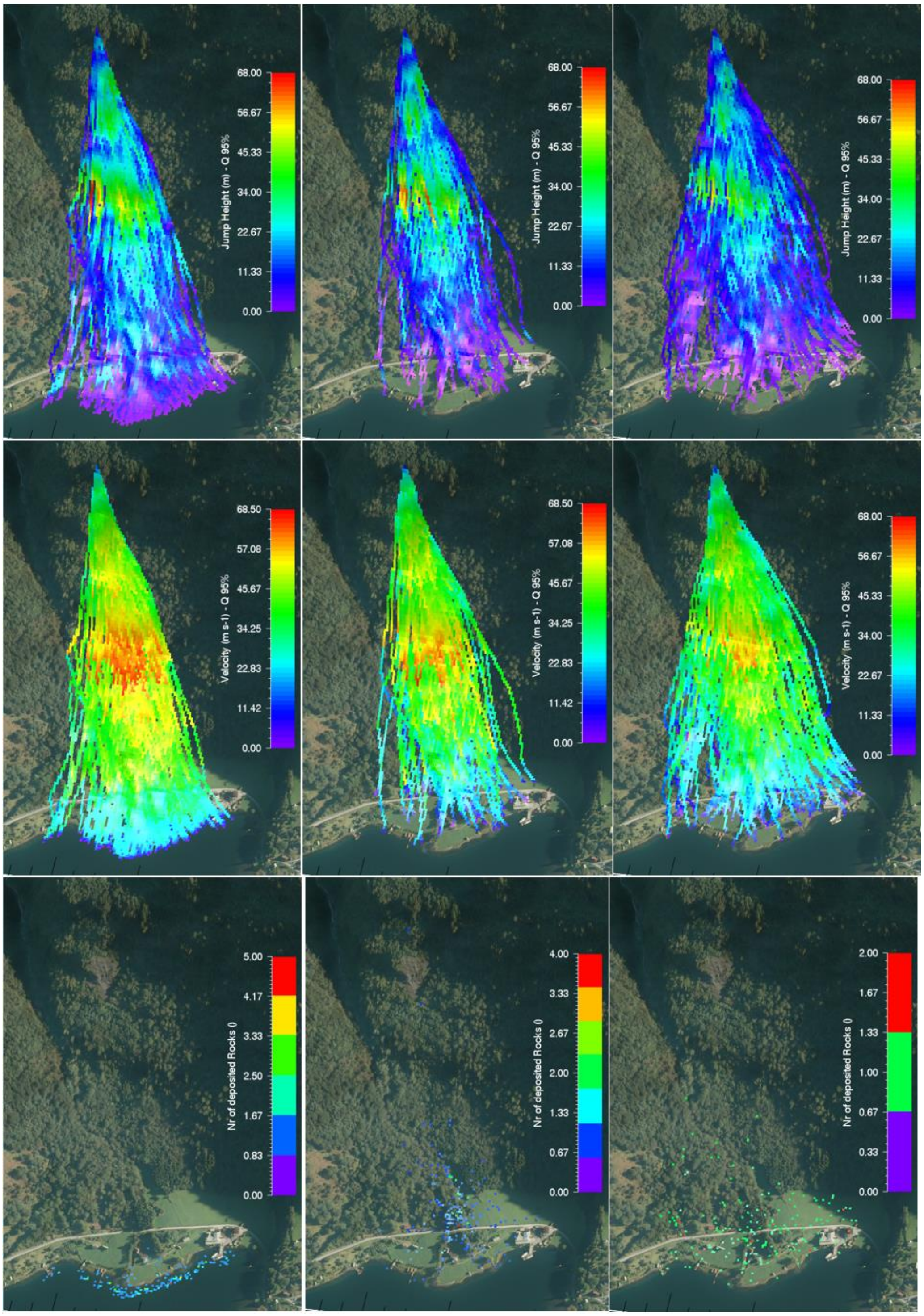


Figure 34: Model outputs of difference rock forms in RAMMS::Rockfall. Equant (left) Flat (middle) and Long (right)

The model results as presented in Table 14 and Figure 34 shows significant differences between Rockyfor3D and RAMMS::Rockfall. For all the different rock form simulations, RAMMS::Rockfall simulated highest jumps happened on the upper part of the slope, while the highest jumps by Rockyfor3D mainly appeared at the flat area. In term of run-out distance, the RAMMS::Rockfall simulations for the equant rocks, which has the most similar shape compare to the spherical shape, came out with longest run-out distances. Most of the rocks deposited in the water or close to the water area (see Figure 34). While in Rockyfor3D, the spherical rocks stopped earlier than the other rock forms.

The run for equant rocks in RAMMS::Rockfall gave highest energy (max/mean 102741.4/35490.7 KJ), highest jump height (max/mean 67.69/9.37) and highest velocity (max/mean 68.16/35.13) (see Table 14). Rockyfor3D, on the opposite, gave lowest values for all those parameters for the spherical rocks (see Table 13).

The main reason for the difference is probably, Rockyfor3D consider the important parameter for calculating the velocity of the block after rebound is the tangential coefficient of restitution (R_t). As described earlier in the report, R_t is determined by the composition and size of the material covering the surface and the radius of the falling block itself, since for larger rocks the effective surface roughness is lower than for smaller rocks. Compare to other rocks in the Rockyfor3D rock library, even though, the rock volumes are similar, but the spherical rock was treated as smaller rock in term of radius due to its dimension definitions (see Table 8 on page 30). Therefore the effective of the surface roughness for the spherical rocks is higher than the others. While in RAMMS::Rockfall the contact was determined at the contact point between rock corner point and the terrain surface. The radius play less role in the RAMMS::Rockfall.

In term of run-out distance, Rockyfor3D gives longer run-out distance for all rock forms compared to RAMMS::Rockfall. Discussions with Ulrik Domaas at NGI also confirm the overestimation of Rockyfor3D on the run-out distance compare to statistic numbers based on historical rockfall event data.

6.5.2. The matter of forest

During the back analysis calculation steps, the comparison of simulation with and without forest by RAMMS::Rockfall and Rockyfor3D was carried out.

In RAMMS::Rockfall, the forest is parameterized by the effective height of the vegetation layer as well as the drag coefficient. The effective height will define the drag layer height. When the rock's center of mass it is located within the drag layer, a resisting force will acts on it. The forest drag in RAMMS::Rockfall then will be applied homogeneously in the forested area, which is a limitation since the falling rock did not always hit the trees on its track.

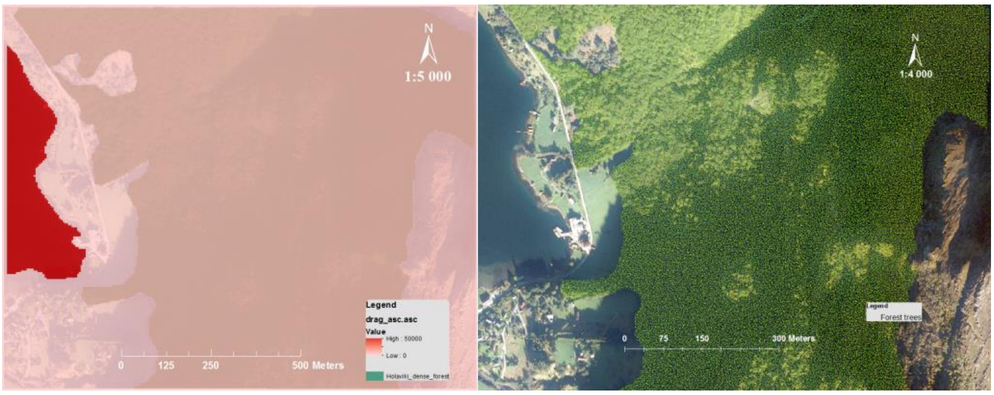


Figure 35: Forest drag in RAMMS::Rockfall (left) vs. tree file in Rockyfor3D (right)

Rockyfor3D builds the forest as tree file with (X,Y,Z) coordinates (see Figure 35). The model user has to provide the positions (in x- and y-coordinates), diameter (in cm) at breast height of the trees (DBH) and the tree types (coniferous trees or broadleaved trees) in the direct surrounding of the simulated rock. If an impact against a tree takes place (only when the rock hit the tree based on position calculation), the rock loses a fraction of its kinetic energy.

Thus, for any forest drag value that was given in RAMMS::Rockfall, the possibility of the forest drag on the falling rock, was either under estimated or overestimated the possibility of the forest drag on the falling rock. Therefore in RAMMS_Sce4 simulation (see Figure 22 on page 37), the effect of the forest on the energy and the jump height of falling rocks was more significant than the effect of forest on the energy of the falling rocks in the Rockyfor3D simulation Rf3D_Sce2 (see Figure 28 on page 45).

6.5.3. Assessments as tool users

Limitation in the possibility to introduce new mean R_n value for the soiltype, no user-defined availability exist in Rockyfor3D. The user can only select soiltype and the associated mean R_n value will be used by the model. The only way to use another mean R_n value is to switch to use another soiltype. RAMMS::Rockfall does suggest physical parameters for different terrain materials but allows user to modify and introduce more appropriate values if available.

It is not clear how Rockyfor3D randomly change the rock volume within +/-5% by changing the rock's initial three dimensions. The testing showed that in the scenario where there is no forest and there is no change in the parameter setting of each simulation run, the result of those simulation runs are identical.

File management, there is a need to switch back and fore between File Explorer, ArcGIS converting processing. One can prepare data in either ArcGIS or ASCII format before running the simulations in Rockyfor3D, but then the user has to use ArcGIS to visualise the results. RAMMS::Rockfall, on the other hand, is an integrated tools where users could modify parameters and test all scenario simulation in the tools. The results could be visualised both in 2D and 3D using the tool.

The current version (Rockyfor3D v5.2.1) allows a "rapid automatic simulation", which only requires a Digital Elevation Model as input. All parameters related to surface roughness and elasticity are calculated automatically, using pessimistic values. The new GUI also allows defining directly the form and the dimensions of the blocks to be simulated. These improvements have been implemented on demand of the participants of the training courses.

7. Study summary and main conclusions

Back analysis calculations show the differences in classifying characteristic of terrain surface, the terrain material (as called in RAMMS::Rockfall) and the soil types (as called in Rockyfor3D). For RAMMS::rockfall the most suitable general terrain material was selected as "hard, in order to compute the rockfall event" while for Rockyfor3D it had to be medium compact soil (soiltye 3 in Rockyfor3D). Therefore, which friction parameters associated with the terrain in each model, are more important than how the terrain materials/soiltypes were called.

The effect of rock forms and forest on the energy and run-out distance of the falling rock were the mains factors that lead to the differences in the simulation results of the two models.

In RAMMS::Rockfall the rock corner points define the contact with the terrain surface and consequently define the initial velocity of the next move, while in Rockyfor3D the radius of the rock was used both to calculate the penetration depth and the after bouncing velocity. Therefore RAMMS::Rockfall was able to simulate more complex motion of the rock.

In the stage of contact between the falling rock with the terrain, RAMMS::Rockfall focuses on building rock form more than the terrain roughness. On the other hand, Rockyfor3D always uses a spherical rock shape for calculating the rebound on the slope surface, therefore the surface roughness need to be defined as accurate as possible in the input data.

The contact of the rock with the terrain surface: in RAMMS::Rockfall, it is detected by continually measuring the vertical gap length between the rock body's corner points and the terrain projections. While in Rockyfor3D, only the position of the rock center of mass is calculated to detect the contact to the terrain surface. Hence, with high resolution of input DEM, the contact of large rocks, with axis lengths are larger than DEM resolution size, can be fully detected using RAMMS::Rockfall.

During contact, the penetration depth was introduced in both RAMMS::Rockfall and Rockyfor3D. In additional, a slip dependant friction was introduced in RAMMS::Rockfall to simulate the sliding of the rock-body as it ploughs into the soft earth cover.

In the calculation of impact against tree, while the RAMMS::Rockfall only considers forest as a homogenously distributed friction layer which acts as linearly proportional to the rock velocity (but in the opposite direction), the Rockyfor3D on the other hand, treats the impact against tree dependent on horizontal and vertical position of contact along with the angle of contact. Even more, Rockyfor3D looks at position of trees in the forest with individual x- and y-coordinates together with the diameter of the tree stem at breast height. This is the advantage of Rockyfor3D compared to RAMMS::Rockfall.

Fragmentation law is not yet implemented in either RAMMS::Rockfall or Rockyfor3D.

The suggestion to have the state-of-the-art model is to combine two models. Either implement the advantages of computation forest impact from the Rockyfor3D into the

RAMMS::Rockfall existing model or take into account the advantages of using cloud of points rock body in contact of terrain surface from the RAMMS::Rockfall into the Rockyfor3D.

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Appendixes

Annexe II in (Dorren, 2012) - Examples of parameter values for different slope surface types

Photo	rg70	rg20	rg10	soiltype
	0	0	0.05	6
	0	0.05	0.1	5
	0.25	0.5	0.9	4
	0.03	0.05	0.05	3
	0.05	0.05	0.1	4

	0.05	0.1	0.2	4
	0.03	0.03	0.03	3
	0	0	0.05	3
	0	0	0	7
	0.15	0.15	0.25	4
	0.1	0.35	0.15	4

	0	0	0	1
	100	100	100	0

Detail data of Hola_Sce4C_R93

t	x	y	z	p0	p1	p2	p3	vx	vy	vz	wx	wy	wz	Etot	Ekin	Ekintrans	Ekinrot	zt	Fn	Ft	Slippage	mu_s	v_res	w_res	jumpH	projDist	Jc	JH_Jc	SD
23.14	360466.4	6766693	36.791	-0.02	0.802	-0.585	-0.118	-34.68	-2.188	-15.272	28.628	3.169	2.704	55018.43	40253.5	29469.05	10784.44	35.413	31301.53	13607.16	0.43	1.391	37.956	28.929	1.378	528.701	0.139	10.293	74.083
23.16	360465.7	6766693	36.483	-0.227	0.767	-0.594	0.081	-34.663	-2.187	-15.46	28.739	3.593	1.364	54989.58	40347.98	29563.54	10784.44	35.273	0	0	0.011	0.579	38.017	28.995	1.211	529.396	0	0	0
23.18	360465.1	6766693	36.367	-0.413	0.681	-0.567	0.209	-30.878	-10.597	-2.675	22.708	-3.031	2.539	43480.24	28885.37	21946	6939.375	35.121	0	0	0.061	0.718	32.755	23.049	1.246	530.055	0	0	0
23.2	360464.4	6766693	36.311	-0.572	0.556	-0.52	0.307	-30.863	-10.592	-2.87	22.77	-2.164	3.162	43458.78	28886.17	21946.79	6939.375	34.967	0	0	0.002	0.554	32.756	23.09	1.344	530.708	0	0	0
23.22	360463.8	6766693	36.252	-0.696	0.396	-0.451	0.395	-30.848	-10.586	-3.065	22.828	-1.208	3.506	43437.32	28888.53	21949.15	6939.375	34.815	0	0	0	0.55	32.758	23.127	1.437	531.36	0	0	0
23.24	360463.2	6766692	36.189	-0.778	0.212	-0.364	0.467	-30.833	-10.581	-3.259	22.886	-0.241	3.564	43415.86	28892.44	21953.07	6939.375	34.664	0	0	0	0.55	32.76	23.163	1.524	532.012	0	0	0
23.26	360462.6	6766692	36.231	-0.82	0.034	-0.236	0.52	-27.926	-8.466	3.813	22.796	-3.12	1.105	39095.03	24554.8	17714.61	6840.194	34.529	0	0	0.052	0.692	29.429	23.035	1.702	532.613	0	0	0
23.28	360462.1	6766692	36.305	-0.822	-0.145	-0.093	0.542	-27.912	-8.462	3.615	22.843	-2.598	1.864	39077.72	24507.69	17667.5	6840.194	34.398	0	0	0.001	0.554	29.389	23.065	1.907	533.197	0	0	0
23.3	360461.5	6766692	36.375	-0.782	-0.321	0.049	0.532	-27.898	-8.457	3.417	22.884	-1.927	2.424	39060.47	24462.22	17622.02	6840.194	34.27	0	0	0	0.55	29.352	23.092	2.106	533.78	0	0	0
23.32	360461	6766692	36.442	-0.701	-0.485	0.183	0.49	-27.885	-8.453	3.219	22.922	-1.169	2.76	39043.25	24418.37	17578.18	6840.194	34.142	0	0	0	0.55	29.315	23.117	2.3	534.363	0	0	0
23.34	360460.4	6766692	36.504	-0.583	-0.628	0.301	0.418	-27.871	-8.449	3.021	22.959	-0.387	2.865	39026.08	24376.16	17535.97	6840.194	34.015	0	0	0	0.55	29.28	23.141	2.489	534.945	0	0	0
23.36	360459.8	6766691	36.563	-0.435	-0.741	0.397	0.321	-27.857	-8.445	2.823	22.997	0.36	2.749	39008.95	24335.57	17495.38	6840.194	33.865	0	0	0	0.55	29.246	23.163	2.698	535.528	0	0	0
23.38	360459.3	6766691	36.617	-0.264	-0.819	0.467	0.205	-27.844	-8.441	2.626	23.035	1.018	2.438	38991.86	24296.61	17456.42	6840.194	33.656	0	0	0	0.55	29.213	23.186	2.961	536.11	0	0	0
23.4	360458.7	6766691	36.668	-0.08	-0.856	0.505	0.076	-27.83	-8.437	2.428	23.072	1.546	1.97	38974.8	24259.28	17419.08	6840.194	33.45	0	0	0	0.55	29.182	23.207	3.218	536.692	0	0	0
23.42	360458.2	6766691	36.714	0.109	-0.851	0.51	-0.059	-27.816	-8.433	2.231	23.106	1.914	1.395	38957.78	24223.56	17383.36	6840.194	33.247	0	0	0	0.55	29.152	23.227	3.467	537.273	0	0	0
23.44	360457.6	6766691	36.757	0.291	-0.804	0.483	-0.191	-27.803	-8.428	2.034	23.137	2.109	0.762	38940.8	24189.46	17349.26	6840.194	33.047	0	0	0	0.55	29.123	23.245	3.71	537.854	0	0	0
23.46	360457.1	6766691	36.795	0.457	-0.716	0.423	-0.314	-27.789	-8.424	1.837	23.164	2.128	0.125	38923.85	24156.97	17316.78	6840.194	32.85	0	0	0	0.55	29.096	23.261	3.945	538.435	0	0	0
23.48	360456.5	6766690	36.83	0.599	-0.593	0.336	-0.421	-27.776	-8.42	1.64	23.186	1.986	-0.468	38906.93	24126.1	17285.91	6840.194	32.657	0	0	0	0.55	29.07	23.275	4.173	539.016	0	0	0
23.5	360455.9	6766690	36.861	0.707	-0.441	0.225	-0.504	-27.762	-8.416	1.443	23.205	1.705	-0.975	38890.04	24096.84	17256.65	6840.194	32.466	0	0	0	0.55	29.046	23.288	4.395	539.596	0	0	0
23.52	360455.4	6766690	36.888	0.777	-0.269	0.098	-0.561	-27.749	-8.412	1.246	23.221	1.319	-1.366	38873.18	24069.19	17229	6840.194	32.279	0	0	0	0.55	29.022	23.298	4.609	540.176	0	0	0
23.54	360454.8	6766690	36.911	0.805	-0.085	-0.039	-0.586	-27.735	-8.408	1.049	23.235	0.866	-1.62	38856.34	24043.15	17202.95	6840.194	32.083	0	0	0	0.55	29	23.308	4.828	540.756	0	0	0
23.56	360454.3	6766690	36.93	0.789	0.101	-0.178	-0.58	-27.728	-8.406	0.852	23.249	0.386	-1.73	38847.93	24027.11	17186.92	6840.194	31.87	0	0	0	0.55	28.987	23.317	5.06	541.335	0	0	0
23.58	360453.7	6766690	36.945	0.73	0.278	-0.312	-0.541	-27.728	-8.406	0.656	23.263	-0.082	-1.699	38847.93	24021.06	17180.86	6840.194	31.661	0	0	0	0.55	28.982	23.325	5.284	541.915	0	0	0
23.6	360453.2	6766689	36.956	0.632	0.438	-0.431	-0.472	-27.728	-8.406	0.46	23.277	-0.505	-1.542	38847.93	24016.58	17176.38	6840.194	31.456	0	0	0	0.55	28.978	23.334	5.5	542.494	0	0	0
23.62	360452.6	6766689	36.963	0.5	0.571	-0.531	-0.376	-27.728	-8.406	0.264	23.291	-0.853	-1.281	38847.93	24013.67	17173.48	6840.194	31.256	0	0	0	0.55	28.976	23.342	5.708	543.074	0	0	0
23.64	360452.1	6766689	36.967	0.341	0.671	-0.606	-0.259	-27.728	-8.406	0.068	23.304	-1.106	-0.944	38847.93	24012.34	17172.15	6840.194	31.06	0	0	0	0.55	28.974	23.349	5.907	543.653	0	0	0
23.66	360451.5	6766689	36.966	0.165	0.731	-0.65	-0.127	-27.728	-8.406	-0.129	23.316	-1.254	-0.565	38847.93	24012.59	17172.39	6840.194	30.869	0	0	0	0.55	28.975	23.356	6.097	544.233	0	0	0
23.68	360451	6766689	36.962	-0.02	0.75	-0.661	0.014	-27.728	-8.406	-0.325	23.326	-1.293	-0.174	38847.93	24014.41	17174.21	6840.194	30.682	0	0	0	0.55	28.976	23.362	6.28	544.812	0	0	0
23.7	360450.4	6766689	36.953	-0.203	0.725	-0.64	0.155	-27.728	-8.406	-0.521	23.334	-1.23	0.196	38847.93	24017.8	17177.61	6840.194	30.5	0	0	0	0.55	28.979	23.368	6.454	545.392	0	0	0
23.72	360449.8	6766688	36.941	-0.373	0.659	-0.586	0.289	-27.728	-8.406	-0.717	23.342	-1.078	0.519	38847.93	24022.77	17182.57	6840.194	30.31	0	0	0	0.55	28.983	23.372	6.631	545.971	0	0	0
23.74	360449.3	6766688	36.924	-0.523	0.554	-0.502	0.409	-27.728	-8.406	-0.913	23.348	-0.857	0.775	38847.93	24029.31	17189.12	6840.194	30.094	0	0	0	0.55	28.989	23.376	6.83	546.551	0	0	0
23.76	360448.7	6766688	36.904	-0.643	0.418	-0.394	0.507	-27.728	-8.406	-1.11	23.353	-0.589	0.95	38847.93	24037.43	17197.24	6840.194	29.88	0	0	0	0.55	28.996	23.38	7.024	547.13	0	0	0
23.78	360448.2	6766688	36.88	-0.727	0.257	-0.265	0.579	-27.728	-8.406	-1.306	23.358	-0.3	1.036	38847.93	24047.12	17206.93	6840.194	29.667	0	0	0	0.55	29.004	23.383	7.213	547.71	0	0	0
23.8	360447.6	6766688	36.852	-0.77	0.081	-0.125	0.621	-27.728	-8.406	-1.502	23.363	-0.012	1.036	38847.93	24058.39	17218.2	6840.194	29.456	0	0	0	0.55	29.013	23.386	7.395	548.289	0	0	0
23.82	360447.1	6766688	36.82	-0.769	-0.101	0.021	0.63	-27.728	-8.406	-1.698	23.368	0.252	0.957	38847.93	24071.24	17231.04	6840.194	29.247	0	0	0	0.55	29.024	23.389	7.573	548.869	0	0	0
23.84	360446.5	6766687	36.784	-0.726	-0.279	0.165	0.607	-27.728	-8.406	-1.894	23.374	0.473	0.811	38847.93	24085.65	17245.46	6840.194	29.04	0	0	0	0.55	29.036	23.392	7.744	549.448	0	0	0
23.86	360446	6766687	36.744	-0.642	-0.442	0.297	0.551	-27.728	-8.406	-2.091	23.378	0.64	0.616	38847.93	24101.65	17261.45	6840.194	28.834	0	0	0	0.55	29.05	23.395	7.91	550.027	0	0	0
23.88	360445.4	6766687	36.7	-0.522	-0.583	0.412	0.467	-27.728	-8.406	-2.287	23.383	0.742	0.39	38847.93	24119.21	17279.02	6840.194	28.63	0	0	0	0.55	29.064	23.398	8.071	550.607	0	0	0
23.9	360444.9	6766687	36.653	-0.372	-0.692	0.504	0.359	-27.728	-8.406	-2.483	23.387	0.78	0.153	38847.93	24138.36	17298.16	6840.194	28.427	0	0	0	0.55	29.081	23.4	8.226	551.186	0	0	0
23.92	360444.3	6766687	36.601	-0.2	-0.765	0.566	0.233	-27.728	-8.406	-2.679	23.39	0.754	-0.074	38847.93	24159.07	17318.88	6840.194	28.226	0	0	0	0.55	29.098	23.402	8.375	551.766	0	0	0
23.94	360443.7	6766687	36.546	-0.016	-0.796	0.597	0.095	-27.728	-8.406	-2.875	23.393	0.672	-0.276	38847.93	24181.36	17341.17	6840.194	28.027	0	0	0	0.55	29.117	23.404	8.518	552.345	0	0	0
23.96	360443.2	6766686	36.486	0.169	-0.785	0.594	-0.046	-27.728	-8.406	-3.072	23.395	0.546	-0.44	38847.93	24205.23	17365.04	6840.194	27.83	0	0	0	0.55	29.137	23.405	8.656	552.925	0	0	0
23.98	360442.6	6766686	36.423	0.347	-0.731	0.558	-0.184	-27.728	-8.406	-3.268	23.397	0.389	-0.555	38847.93	24230.67	17390.48	6840.194	27.634	0	0	0	0.55	29.158	23.407	8.789	553.504	0	0	0
24	360442.1	6766686	36.355	0.506	-0.638	0.49	-0.31	-27.728	-8.406	-3.464	23.399	0.215	-0.618	38847.93	24257.69	17417.5	6840.194	27.44	0	0	0	0.55	29.181	23.408	8.916	554.084	0	0	0
24.02	360441.5	6766686	36.284	0.639	-0.51	0.395	-0.418	-27.728	-8.406	-3.66	23.401	0.04	-0.628	38847.93	24286.28	17446.09	6840.194	27.247	0	0	0	0.55	29.205	23.409	9.037	554.663	0	0	0
24.04	360441	6766686	36.209	0.738	-0.355	0.278	-0.502	-27.728	-8.406	-3.856	23.402	-0.123	-0.589	38847.93	24316.45	17476.25	6840.194	27.056	0	0	0	0.55	29.23	23.41	9.153	555.243	0	0	0
24.06	360440.4	6766686	36.13	0.797	-0.181	0.145	-0.557	-27.728	-8.406	-4.053	23.404	-0.262	-0.508	38847.93	24348.19	17507.99	6840.194	26.867	0	0	0	0.55	29.256	23.411	9.263	555.822	0	0	0
24.08	360439.9	6766685	36.047	0.814	0.003	0.004	-0.58	-27.728	-8.406	-4.249	23.406	-0.369	-0.395	38847.93	24381.5	17541.31	6840.194	26.681	0	0	0	0.55	29.284	23.412	9.366	556.402	0	0	0
24.1	360439.3	6766685	35.96	0.787	0.187	-0.137	-0.571	-27.728	-8.406	-4.445	23.408	-0.439	-0.261	38847.93	24416.39	17576.2	6840.194	26.498	0	0	0	0.55	29.313	23.413	9.461	556.981	0	0	0
24.12	360438.8	6766685	35.869	0.719	0.36	-0.272	-0.529	-27.728	-8.406	-4.641	23.409	-0.468	-0.119	38847.93	24452.86	17612.66	6840.194	26.317	0	0	0	0.55	29.344	23.414	9.552	557.561	0	0	0
24.14	360438.2	6766685	35.774	0.611	0.514	-0.391	-0.457	-27.728	-8.406	-4.837	23.41	-0.459	0.02	38847.93	24490.9	17650.7	6840.194	26.136	0	0	0	0.55	29.375	23.415	9.638	558.14	0	0	0
24.16	360437.6	6766685	35.676	0.471	0.639	-0.49	-0.359	-27.728	-8.406	-5.034	23.411	-0.416	0.145	38847.93	24530.51	17690.32	6840.194	25.956	0	0	0	0.55	29.408	23.415	9.72	558.719	0	0	0
24.18	360437.1	6766685	35.573	0.306	0.73	-0.562	-0.241	-27.728	-8.406	-5.23	23.412	-0.344	0.249	38847.93	24571.7	17731.51	6840.194	25.776	0	0	0	0.55	29.443	23.416	9.797	559.299	0	0	0
24.2	360436.5	6766684	35.466	0.125	0.781	-0.603	-0.108	-27.728	-8.406	-5.426	23.413	-0.252	0.324	38847.93	24614.46	17774.27	6840.194	25.597	0	0	0	0.55	29.478	23.417	9.869	559.878	0	0	0
24.22	360436	6766684	35.356	-0.062	0.789	-0.611	0.031	-27.728	-8.406	-5.622	23.414	-0.149	0.368	38847.93	24658.8	17818.61	6840.194	25.42	0	0	0	0.55	29.515	23.417	9.936	560.458	0	0	0
24.24	360435.4	6766684	35.241	-0.245	0.754	-0.586	0.17	-27.728	-8.406	-5.818	23.414	-0.043	0.38	38847.93	24704.72	17864.52	6840.194	25.242	0	0	0	0.55	29.553	23.417	9.999	561.037	0	0	0
24.26	360434.9	6766684	35.123	-0.414	0.677	-0.528	0.301	-27.728	-8.406	-6.015	23.415	0.057	0.361	38847.93	24752.21	17912.01	6840.194	25.066	0	0	0	0.55	29.592	23.418	10.057	561.617	0	0	0

24.28	360434.3	6766684	35.001	-0.56	0.564	-0.442	0.415	-27.728	-8.406	-6.211	23.416	0.144	0.316	38847.93	24801.27	17961.07	6840.194	24.89	0	0	0	0.55	29.633	23.418	10.111	562.196	0	0	0
24.3	360433.8	6766684	34.875	-0.675	0.421	-0.331	0.508	-27.728	-8.406	-6.407	23.416	0.212	0.251	38847.93	24851.91	18011.71	6840.194	24.715	0	0	0	0.55	29.674	23.419	10.16	562.776	0	0	0
24.32	360433.2	6766683	34.745	-0.752	0.254	-0.202	0.573	-27.728	-8.406	-6.603	23.417	0.258	0.172	38847.93	24904.12	18063.93	6840.194	24.541	0	0	0	0.55	29.717	23.419	10.204	563.355	0	0	0
24.34	360432.7	6766683	34.611	-0.788	0.074	-0.062	0.608	-27.728	-8.406	-6.799	23.417	0.28	0.087	38847.93	24957.91	18117.71	6840.194	24.367	0	0	0	0.55	29.761	23.419	10.243	563.935	0	0	0
24.36	360432.1	6766683	34.473	-0.78	-0.11	0.082	0.611	-27.728	-8.406	-6.996	23.418	0.279	0.003	38847.93	25013.27	18173.08	6840.194	24.195	0	0	0	0.55	29.807	23.42	10.278	564.514	0	0	0
24.38	360431.5	6766683	34.331	-0.729	-0.288	0.222	0.58	-27.728	-8.406	-7.192	23.418	0.257	-0.075	38847.93	25070.21	18230.01	6840.194	24.023	0	0	0	0.55	29.854	23.42	10.308	565.094	0	0	0
24.4	360431	6766683	34.185	-0.638	-0.45	0.349	0.519	-27.728	-8.406	-7.388	23.419	0.216	-0.14	38847.93	25128.72	18288.52	6840.194	23.852	0	0	0	0.55	29.901	23.42	10.333	565.673	0	0	0
24.42	360430.4	6766683	34.035	-0.511	-0.587	0.458	0.429	-27.728	-8.406	-7.584	23.419	0.163	-0.188	38847.93	25188.81	18348.61	6840.194	23.681	0	0	0	0.55	29.951	23.42	10.354	566.253	0	0	0
24.44	360429.9	6766682	33.882	-0.356	-0.692	0.543	0.317	-27.728	-8.406	-7.78	23.419	0.101	-0.218	38847.93	25250.47	18410.27	6840.194	23.512	0	0	0	0.55	30.001	23.42	10.37	566.832	0	0	0
24.46	360429.3	6766682	33.724	-0.182	-0.758	0.597	0.188	-27.728	-8.406	-7.977	23.419	0.037	-0.229	38847.93	25313.7	18473.51	6840.194	23.345	0	0	0	0.55	30.052	23.421	10.379	567.411	0	0	0
24.48	360428.8	6766682	33.563	0.003	-0.783	0.62	0.048	-27.728	-8.406	-8.173	23.42	-0.024	-0.221	38847.93	25378.51	18538.32	6840.194	23.179	0	0	0	0.55	30.105	23.421	10.384	567.991	0	0	0
24.5	360428.2	6766682	33.397	0.188	-0.765	0.609	-0.093	-27.728	-8.406	-8.369	23.42	-0.078	-0.196	38847.93	25444.9	18604.71	6840.194	23.013	0	0	0	0.55	30.159	23.421	10.384	568.57	0	0	0
24.52	360427.7	6766682	33.228	0.363	-0.705	0.565	-0.229	-27.728	-8.406	-8.565	23.42	-0.121	-0.159	38847.93	25512.86	18672.67	6840.194	22.848	0	0	0	0.55	30.214	23.421	10.38	569.15	0	0	0
24.54	360427.1	6766682	33.055	0.518	-0.606	0.49	-0.352	-27.728	-8.406	-8.761	23.42	-0.152	-0.113	38847.93	25582.4	18742.2	6840.194	22.683	0	0	0	0.55	30.27	23.421	10.372	569.729	0	0	0
24.56	360426.6	6766681	32.877	0.646	-0.474	0.389	-0.456	-27.728	-8.406	-8.958	23.421	-0.168	-0.062	38847.93	25653.51	18813.31	6840.194	22.518	0	0	0	0.55	30.327	23.421	10.359	570.309	0	0	0
24.58	360426	6766681	32.696	0.738	-0.315	0.267	-0.534	-27.728	-8.406	-9.154	23.421	-0.169	-0.01	38847.93	25726.19	18886	6840.194	22.353	0	0	0	0.55	30.386	23.421	10.343	570.888	0	0	0
24.6	360425.4	6766681	32.511	0.79	-0.139	0.13	-0.583	-27.728	-8.406	-9.35	23.421	-0.158	0.037	38847.93	25800.45	18960.26	6840.194	22.19	0	0	0	0.55	30.446	23.421	10.322	571.468	0	0	0
24.62	360424.9	6766681	32.322	0.799	0.045	-0.013	-0.6	-27.728	-8.406	-9.546	23.421	-0.135	0.078	38847.93	25876.29	19036.09	6840.194	22.026	0	0	0	0.55	30.506	23.421	10.296	572.047	0	0	0
24.64	360424.3	6766681	32.129	0.764	0.226	-0.155	-0.584	-27.728	-8.406	-9.742	23.421	-0.104	0.109	38847.93	25953.7	19113.5	6840.194	21.863	0	0	0	0.55	30.568	23.422	10.267	572.627	0	0	0
24.66	360423.8	6766681	31.933	0.688	0.396	-0.288	-0.536	-27.728	-8.406	-9.939	23.421	-0.068	0.129	38847.93	26032.68	19192.49	6840.194	21.7	0	0	0	0.55	30.631	23.422	10.233	573.206	0	0	0
24.68	360423.2	6766680	31.732	0.574	0.544	-0.406	-0.458	-27.728	-8.406	-10.135	23.421	-0.029	0.137	38847.93	26113.24	19273.05	6840.194	21.537	0	0	0	0.55	30.696	23.422	10.194	573.786	0	0	0
24.7	360422.7	6766680	31.527	0.429	0.663	-0.501	-0.355	-27.728	-8.406	-10.331	23.421	0.008	0.134	38847.93	26195.37	19355.18	6840.194	21.375	0	0	0	0.55	30.761	23.422	10.152	574.365	0	0	0
24.72	360422.1	6766680	31.319	0.261	0.745	-0.568	-0.233	-27.728	-8.406	-10.527	23.421	0.042	0.121	38847.93	26279.08	19438.89	6840.194	21.213	0	0	0	0.55	30.827	23.422	10.105	574.945	0	0	0
24.74	360421.6	6766680	31.106	0.078	0.787	-0.604	-0.098	-27.728	-8.406	-10.723	23.421	0.069	0.1	38847.93	26364.37	19524.17	6840.194	21.036	0	0	0	0.55	30.895	23.422	10.07	575.524	0	0	0
24.76	360421	6766680	30.89	-0.109	0.786	-0.607	0.043	-27.728	-8.406	-10.92	23.422	0.089	0.073	38847.93	26451.22	19611.03	6840.194	20.857	0	0	0	0.55	30.964	23.422	10.033	576.104	0	0	0
24.78	360420.5	6766680	30.669	-0.29	0.743	-0.576	0.181	-27.728	-8.406	-11.116	23.422	0.1	0.043	38847.93	26539.66	19699.46	6840.194	20.68	0	0	0	0.55	31.033	23.422	9.989	576.683	0	0	0
24.8	360419.9	6766679	30.445	-0.455	0.659	-0.513	0.31	-27.728	-8.406	-11.312	23.422	0.102	0.012	38847.93	26629.66	19789.47	6840.194	20.513	0	0	0	0.55	31.104	23.422	9.932	577.262	0	0	0
24.82	360419.3	6766679	30.217	-0.595	0.539	-0.423	0.421	-27.728	-8.406	-11.508	23.422	0.097	-0.018	38847.93	26721.25	19881.05	6840.194	20.376	0	0	0	0.55	31.176	23.422	9.841	577.842	0	0	0
24.84	360418.8	6766679	29.985	-0.702	0.39	-0.309	0.51	-27.728	-8.406	-11.704	23.422	0.084	-0.043	38847.93	26814.4	19974.21	6840.194	20.24	0	0	0	0.55	31.249	23.422	9.745	578.421	0	0	0
24.86	360418.2	6766679	29.749	-0.771	0.219	-0.177	0.57	-27.728	-8.406	-11.901	23.422	0.066	-0.063	38847.93	26909.14	20068.94	6840.194	20.104	0	0	0	0.55	31.323	23.422	9.645	579.001	0	0	0
24.88	360417.7	6766679	29.509	-0.798	0.037	-0.036	0.6	-27.728	-8.406	-12.097	23.422	0.045	-0.076	38847.93	27005.44	20165.25	6840.194	19.969	0	0	0	0.55	31.398	23.422	9.539	579.58	0	0	0
24.9	360417.1	6766679	29.265	-0.782	-0.147	0.107	0.597	-27.728	-8.406	-12.293	23.422	0.022	-0.082	38847.93	27103.33	20263.13	6840.194	19.835	0	0	0	0.55	31.474	23.422	9.429	580.16	0	0	0
24.92	360416.6	6766678	29.017	-0.722	-0.322	0.245	0.561	-27.728	-8.406	-12.489	23.422	-0.001	-0.082	38847.93	27202.78	20362.59	6840.194	19.702	0	0	0	0.55	31.551	23.422	9.315	580.739	0	0	0
24.94	360416	6766678	28.765	-0.623	-0.481	0.369	0.494	-27.728	-8.406	-12.685	23.422	-0.022	-0.075	38847.93	27303.81	20463.62	6840.194	19.57	0	0	0	0.55	31.63	23.422	9.195	581.319	0	0	0
24.96	360415.5	6766678	28.509	-0.491	-0.612	0.473	0.4	-27.728	-8.406	-12.882	23.422	-0.039	-0.063	38847.93	27406.42	20566.23	6840.194	19.438	0	0	0	0.55	31.709	23.422	9.071	581.898	0	0	0
24.98	360414.9	6766678	28.25	-0.331	-0.71	0.552	0.285	-27.728	-8.406	-13.078	23.422	-0.052	-0.047	38847.93	27510.6	20670.41	6840.194	19.307	0	0	0	0.55	31.789	23.422	8.943	582.478	0	0	0
25	360414.4	6766678	27.986	-0.153	-0.769	0.601	0.154	-27.728	-8.406	-13.274	23.422	-0.059	-0.029	38847.93	27616.36	20776.16	6840.194	19.177	0	0	0	0.55	31.87	23.422	8.81	583.057	0	0	0
25.02	360413.8	6766678	27.719	0.033	-0.786	0.617	0.014	-27.728	-8.406	-13.47	23.422	-0.062	-0.01	38847.93	27723.69	20883.49	6840.194	19.047	0	0	0	0.55	31.952	23.422	8.672	583.637	0	0	0
25.04	360413.2	6766677	27.448	0.217	-0.76	0.599	-0.127	-27.728	-8.406	-13.666	23.422	-0.059	0.008	38847.93	27832.59	20992.4	6840.194	18.919	0	0	0	0.55	32.036	23.422	8.529	584.216	0	0	0
25.06	360412.7	6766677	27.172	0.389	-0.692	0.549	-0.26	-27.728	-8.406	-13.863	23.422	-0.052	0.023	38847.93	27943.07	21102.88	6840.194	18.791	0	0	0	0.55	32.12	23.422	8.382	584.796	0	0	0
25.08	360412.1	6766677	26.893	0.54	-0.587	0.469	-0.38	-27.728	-8.406	-14.059	23.422	-0.042	0.036	38847.93	28055.13	21214.93	6840.194	18.663	0	0	0	0.55	32.205	23.422	8.23	585.375	0	0	0
25.1	360411.6	6766677	26.61	0.662	-0.449	0.363	-0.478	-27.728	-8.406	-14.255	23.422	-0.029	0.045	38847.93	28168.76	21328.56	6840.194	18.537	0	0	0	0.55	32.291	23.422	8.073	585.954	0	0	0
25.12	360411	6766677	26.323	0.747	-0.286	0.238	-0.551	-27.728	-8.406	-14.451	23.422	-0.016	0.049	38847.93	28283.96	21443.77	6840.194	18.411	0	0	0	0.55	32.378	23.422	7.912	586.534	0	0	0
25.14	360410.5	6766676	26.032	0.791	-0.108	0.099	-0.594	-27.728	-8.406	-14.647	23.422	-0.002	0.05	38847.93	28400.74	21560.55	6840.194	18.286	0	0	0	0.55	32.466	23.422	7.746	587.113	0	0	0
25.16	360409.9	6766676	25.737	0.792	0.076	-0.044	-0.604	-27.728	-8.406	-14.844	23.422	0.011	0.046	38847.93	28519.09	21678.9	6840.194	18.176	0	0	0	0.55	32.555	23.422	7.561	587.693	0	0	0
25.18	360409.4	6766676	25.438	0.75	0.256	-0.186	-0.581	-27.728	-8.406	-15.04	23.422	0.022	0.039	38847.93	28639.02	21798.83	6840.194	18.143	0	0	0	0.55	32.645	23.422	7.295	588.272	0	0	0
25.2	360408.8	6766676	25.135	0.666	0.422	-0.316	-0.527	-27.728	-8.406	-15.236	23.422	0.03	0.03	38847.93	28760.53	21920.33	6840.194	18.109	0	0	0	0.55	32.736	23.422	7.026	588.852	0	0	0
25.22	360408.3	6766676	24.829	0.546	0.565	-0.43	-0.444	-27.728	-8.406	-15.432	23.422	0.035	0.019	38847.93	28883.6	22043.41	6840.194	18.073	0	0	0	0.55	32.828	23.422	6.755	589.431	0	0	0
25.24	360407.7	6766676	24.518	0.397	0.678	-0.52	-0.336	-27.728	-8.406	-15.628	23.422	0.037	0.008	38847.93	29008.26	22168.06	6840.194	18.036	0	0	0	0.55	32.92	23.422	6.482	590.011	0	0	0
25.26	360407.1	6766675	24.204	0.225	0.753	-0.581	-0.211	-27.728	-8.406	-15.825	23.422	0.036	-0.003	38847.93	29134.49	22294.29	6840.194	17.997	0	0	0	0.55	33.014	23.422	6.206	590.59	0	0	0
25.28	360406.6	6766675	23.885	0.041	0.787	-0.611	-0.073	-27.728	-8.406	-16.021	23.422	0.032	-0.013	38847.93	29262.29	22422.1	6840.194	17.957	0	0	0	0.55	33.109	23.422	5.928	591.17	0	0	0
25.3	360406	6766675	23.563	-0.145	0.778	-0.607	0.068	-27.728	-8.406	-16.217	23.422	0.026	-0.02	38847.93	29391.67	22551.47	6840.194	17.915	0	0	0	0.55	33.204	23.422	5.647	591.749	0	0	0
25.32	360405.5	6766675	23.236	-0.324	0.727	-0.57	0.205	-27.728	-8.406	-16.413	23.422	0.019	-0.026	38847.93	29522.62	22682.43	6840.194	17.872	0	0	0	0.55	33.3	23.422	5.364	592.329	0	0	0
25.34	360404.9	6766675	22.906	-0.484	0.636	-0.502	0.331	-27.728	-8.406	-16.609	23.422	0.011	-0.029	38847.93	29655.15	22814.95	6840.194	17.827	0	0	0	0.55	33.397	23.422	5.079	592.908	0	0	0
25.36	360404.4	6766675	22.572	-0.619	0.51	-0.406	0.439	-27.728	-8.406	-16.806	23.422	0.002	-0.03	38847.93	29789.25	22949.05	6840.194	17.781	0	0	0	0.55	33.495	23.422	4.791	593.488	0	0	0
25.38	360403.8	6766674	22.234	-0.719	0.356	-0.288	0.523	-27.728	-8.406	-17.002	23.422	-0.005	-0.028	38847.93	29924.92	23084.73	6840.194	17.733	0	0	0	0.55	33.594	23.422	4.501	594.067	0	0	0
25.4	360403.3	6766674	21.892	-0.78	0.183	-0.155	0.578	-27.728	-8.406	-17.198	23.422	-0.012	-0.024	38847.93	30062.18	23221.98	6840.194	17.684	0	0	0	0.55	33.694	23.422	4.208	594.646	0	0	0
25.42	360402.7	6766674	21.546	-0.799	0	-0.012	0.601	-27.728	-8.406	-17.394	23.422	-0.017	-0.019	38847.93	30201	23360.81	6840.194	17.633	0	0	0	0.55	33.795	23.422	3.913	595.226	0	0	0
25.44	360402.2	6766674	21.196	-0.774	-0.183	0.131	0.592	-27.728	-8.406	-17.59	23.422	-0.021	-0.013	38847.93	30341.4	23501.21	6840.194	17.581	0	0	0	0.55	33.896	23.422	3.615	595.805	0	0	0
25.46	360401.6	6766674	20.842	-0.707	-0.356	0.266	0.55	-27.728	-8.406	-17.787	23.422	-0.022	-0.006	38847.93	30483.38	23643.19	6840.194	17.528	0	0	0	0.55	33.998	23.422	3.315	596.385	0	0	0
25.48	360401	6766674	20.485	-0.601	-0.51	0.388	0.478	-27.728	-8.406	-17.983	23.422	-0.022	0.001	38847.93	30626.93	23786.74	6840.194	17.472	0	0	0	0.55	34.101	23.422	3.012	596.964	0	0	0
25.5	360400.5	6766673	20.123	-0.462	-0.636	0.488	0.38	-27.728	-8.406	-18.179	23.422	-0.02	0.007	38847.93	30772.06	23931.86	6840.194	17.416	0	0	0	0.55	34.205	23.422	2.707	597.544	0	0	0
25.52	360399.9	6766673	19.758	-0.298	-0.727	0.561	0.261	-27.728	-8.406	-18.375	23.422	-0.017	0.012	38847.93	30918.76	24078.56	6840.194	17.35	0	0	0	0.547	34.31	23.422	2.407	598.123	0	0	0
25.54	360399.4	6766673	19.388	-0.118	-0.778	0.604	0.128	-27.728	-8.406	-18.571	23.422	-0.012	0.015	38847.93	31067.03	24226.84	6840.194	17.231	0	0	0	0.525	34.415	23.422	2.157	598.703	0	0	0
25.56	360398.8	6766673	19.015	0.069	-0.787	0.614	-0.012	-27.728	-8.406	-18.768	23.422	-0.007	0.017	38847.93	31216.88	24376.69	6840.194	17.113	0	0	0	0.503	34.522	23.422	1.902	599.282	0	0	0
25.58	360398.3	6766673	18.637	0.251	-0.752	0.59	-0.152	-27.728	-8.406	-18.964	23.422	-0.002	0.018	38847.93	31368.31	24528.11	6840.194	16.995	0	0	0	0.481	34.629	23.422	1.643	599.862	0	0	0
25.6	360397.7	6766673	18.291	0.424	-0.675	0.537	-0.276	-26.172	-11.062	-12.265	22.717	-3.174	1.592	33780.27	26439.81	19591.05	6848.757	16.878	21636.78	14130.35	0.347	1.168	30.948	22.993	1.413	600.438	0	0	0
25.62	360397.2	6766672	18.043	0.584	-0.555	0.467	-0.365	-26.172	-11.062	-12.461	22.769	-2.53	2.326	33780.27	26539.04	19690.28	6848.757	16.76	0	0	0.012	0.468	31.026	23.027	1.284	601.006	0	0	0
25.64	360396.7	6766672	17.833	0.711	-0.401	0.372	-0.442	-24.949	-8.139	-4.565	24.627	-2.396	-0.218	29423.39	22266.73	14513.27	7753.461	16.646	28894.26	9073.126	0.313	1.053	26.637	24.745	1.187	601.563	0.13	7.107	54.803

25.66	360396.2	6766672	17.896	0.785	-0.265	0.254	-0.5	-23.916	-6.064	5.693	18.784	-2.27	-1.145	24908.33	17726.17	13114.4	4611.771	16.548	0	0	0.118	0.661	25.321	18.956	1.348	602.064	0	0	0
25.68	360395.7	6766672	18.008	0.825	-0.128	0.133	-0.534	-23.916	-6.064	5.496	18.814	-2.385	-0.565	24908.33	17681.26	13069.49	4611.771	16.453	0	0	0.005	0.39	25.277	18.973	1.556	602.558	0	0	0
25.7	360395.2	6766672	18.116	0.839	0.015	0.01	-0.543	-23.916	-6.064	5.3	18.84	-2.371	0.011	24908.33	17637.93	13026.16	4611.771	16.358	0	0	0	0.36	25.235	18.989	1.758	603.051	0	0	0
25.72	360394.8	6766672	18.22	0.826	0.159	-0.111	-0.53	-23.916	-6.064	5.104	18.863	-2.237	0.553	24908.33	17596.18	12984.41	4611.771	16.263	0	0	0	0.35	25.195	19.003	1.957	603.545	0	0	0
25.74	360394.3	6766672	18.32	0.785	0.3	-0.227	-0.493	-23.916	-6.064	4.908	18.882	-1.996	1.037	24908.33	17556	12944.23	4611.771	16.169	0	0	0	0.35	25.156	19.016	2.151	604.038	0	0	0
25.76	360393.8	6766671	18.416	0.718	0.431	-0.331	-0.435	-23.916	-6.064	4.712	18.899	-1.666	1.44	24908.33	17517.4	12905.62	4611.771	16.076	0	0	0	0.35	25.118	19.027	2.341	604.532	0	0	0
25.78	360393.3	6766671	18.509	0.627	0.549	-0.422	-0.357	-23.916	-6.064	4.515	18.915	-1.269	1.745	24908.33	17480.36	12868.59	4611.771	15.983	0	0	0	0.35	25.082	19.038	2.526	605.025	0	0	0
25.8	360392.8	6766671	18.597	0.516	0.648	-0.494	-0.263	-23.916	-6.064	4.319	18.93	-0.83	1.943	24908.33	17444.91	12833.14	4611.771	15.89	0	0	0	0.35	25.048	19.048	2.707	605.519	0	0	0
25.82	360392.4	6766671	18.681	0.389	0.725	-0.546	-0.157	-23.916	-6.064	4.123	18.945	-0.372	2.03	24908.33	17411.03	12799.26	4611.771	15.798	0	0	0	0.35	25.015	19.058	2.883	606.012	0	0	0
25.84	360391.9	6766671	18.762	0.249	0.778	-0.575	-0.043	-23.916	-6.064	3.927	18.961	0.078	2.006	24908.33	17378.72	12766.95	4611.771	15.706	0	0	0	0.35	24.983	19.067	3.056	606.505	0	0	0
25.86	360391.4	6766671	18.839	0.102	0.804	-0.581	0.075	-23.916	-6.064	3.731	18.978	0.498	1.88	24908.33	17347.99	12736.22	4611.771	15.615	0	0	0	0.35	24.953	19.077	3.223	606.999	0	0	0
25.88	360390.9	6766671	18.911	-0.046	0.802	-0.563	0.193	-23.916	-6.064	3.534	18.994	0.868	1.663	24908.33	17318.84	12707.07	4611.771	15.524	0	0	0	0.35	24.924	19.087	3.387	607.492	0	0	0
25.9	360390.5	6766671	18.98	-0.192	0.773	-0.521	0.306	-23.916	-6.064	3.338	19.01	1.172	1.373	24908.33	17291.25	12679.48	4611.771	15.434	0	0	0	0.35	24.897	19.096	3.546	607.986	0	0	0
25.92	360390	6766670	19.045	-0.328	0.718	-0.458	0.409	-23.916	-6.064	3.142	19.026	1.397	1.028	24908.33	17265.25	12653.48	4611.771	15.344	0	0	0	0.35	24.872	19.105	3.701	608.479	0	0	0
25.94	360389.5	6766670	19.106	-0.451	0.638	-0.375	0.499	-23.916	-6.064	2.946	19.04	1.536	0.649	24908.33	17240.82	12629.05	4611.771	15.235	0	0	0	0.35	24.848	19.113	3.87	608.973	0	0	0
25.96	360389	6766670	19.163	-0.555	0.536	-0.275	0.573	-23.916	-6.064	2.75	19.053	1.587	0.258	24908.33	17217.96	12606.19	4611.771	15.127	0	0	0	0.35	24.825	19.121	4.035	609.466	0	0	0
25.98	360388.5	6766670	19.216	-0.638	0.417	-0.163	0.626	-23.916	-6.064	2.553	19.064	1.552	-0.123	24908.33	17196.68	12584.91	4611.771	15.02	0	0	0	0.35	24.804	19.128	4.196	609.96	0	0	0
26	360388.1	6766670	19.265	-0.696	0.285	-0.043	0.658	-23.916	-6.064	2.357	19.074	1.437	-0.476	24908.33	17176.97	12565.2	4611.771	14.912	0	0	0	0.35	24.785	19.134	4.353	610.453	0	0	0
26.02	360387.6	6766670	19.31	-0.727	0.143	0.082	0.667	-23.916	-6.064	2.161	19.082	1.254	-0.783	24908.33	17158.84	12547.07	4611.771	14.794	0	0	0	0.35	24.767	19.139	4.516	610.947	0	0	0
26.04	360387.1	6766670	19.351	-0.73	-0.001	0.207	0.652	-23.916	-6.064	1.965	19.089	1.016	-1.031	24908.33	17142.28	12530.51	4611.771	14.678	0	0	0	0.35	24.751	19.144	4.674	611.44	0	0	0
26.06	360386.6	6766670	19.388	-0.704	-0.144	0.326	0.614	-23.916	-6.064	1.769	19.096	0.739	-1.21	24908.33	17127.3	12515.53	4611.771	14.562	0	0	0	0.35	24.736	19.149	4.827	611.934	0	0	0
26.08	360386.2	6766670	19.422	-0.652	-0.279	0.435	0.554	-23.916	-6.064	1.572	19.103	0.439	-1.315	24908.33	17113.89	12502.12	4611.771	14.447	0	0	0	0.35	24.723	19.153	4.975	612.427	0	0	0
26.1	360385.7	6766669	19.451	-0.575	-0.402	0.531	0.475	-23.916	-6.064	1.376	19.11	0.134	-1.345	24908.33	17102.05	12490.28	4611.771	14.333	0	0	0	0.35	24.711	19.158	5.118	612.921	0	0	0
26.12	360385.2	6766669	19.477	-0.476	-0.509	0.609	0.378	-23.916	-6.064	1.18	19.117	-0.161	-1.303	24908.33	17091.8	12480.03	4611.771	14.22	0	0	0	0.35	24.701	19.162	5.257	613.414	0	0	0
26.14	360384.7	6766669	19.499	-0.359	-0.595	0.667	0.268	-23.916	-6.064	0.984	19.124	-0.429	-1.194	24908.33	17083.11	12471.34	4611.771	14.108	0	0	0	0.35	24.692	19.166	5.39	613.908	0	0	0
26.16	360384.2	6766669	19.516	-0.228	-0.657	0.703	0.148	-23.916	-6.064	0.788	19.131	-0.66	-1.028	24908.33	17076	12464.23	4611.771	13.997	0	0	0	0.35	24.685	19.17	5.519	614.401	0	0	0
26.18	360383.8	6766669	19.53	-0.088	-0.693	0.715	0.023	-23.916	-6.064	0.591	19.138	-0.841	-0.819	24908.33	17070.47	12458.7	4611.771	13.887	0	0	0	0.35	24.68	19.174	5.643	614.894	0	0	0
26.2	360383.3	6766669	19.54	0.055	-0.702	0.702	-0.103	-23.916	-6.064	0.395	19.145	-0.968	-0.578	24908.33	17066.51	12454.74	4611.771	13.778	0	0	0	0.35	24.676	19.178	5.762	615.388	0	0	0
26.22	360382.8	6766669	19.546	0.197	-0.684	0.666	-0.225	-23.916	-6.064	0.199	19.151	-1.036	-0.321	24908.33	17064.12	12452.35	4611.771	13.67	0	0	0	0.35	24.673	19.182	5.876	615.881	0	0	0
26.24	360382.3	6766669	19.548	0.332	-0.638	0.607	-0.339	-23.916	-6.064	0.003	19.156	-1.045	-0.063	24908.33	17063.31	12451.54	4611.771	13.562	0	0	0	0.35	24.673	19.185	5.985	616.375	0	0	0
26.26	360381.8	6766668	19.546	0.455	-0.567	0.527	-0.44	-23.916	-6.064	-0.193	19.161	-0.999	0.184	24908.33	17064.08	12452.31	4611.771	13.456	0	0	0	0.35	24.673	19.188	6.09	616.868	0	0	0
26.28	360381.4	6766668	19.54	0.561	-0.473	0.43	-0.526	-23.916	-6.064	-0.39	19.165	-0.902	0.406	24908.33	17066.42	12454.65	4611.771	13.351	0	0	0	0.35	24.676	19.19	6.19	617.362	0	0	0
26.3	360380.9	6766668	19.53	0.646	-0.361	0.319	-0.592	-23.916	-6.064	-0.586	19.168	-0.764	0.594	24908.33	17070.33	12458.56	4611.771	13.246	0	0	0	0.35	24.68	19.193	6.284	617.855	0	0	0
26.32	360380.4	6766668	19.517	0.708	-0.233	0.198	-0.637	-23.916	-6.064	-0.782	19.171	-0.593	0.739	24908.33	17075.82	12464.05	4611.771	13.142	0	0	0	0.35	24.685	19.195	6.374	618.349	0	0	0
26.34	360379.9	6766668	19.499	0.743	-0.096	0.071	-0.658	-23.916	-6.064	-0.978	19.174	-0.401	0.836	24908.33	17082.89	12471.12	4611.771	13.04	0	0	0	0.35	24.692	19.197	6.459	618.842	0	0	0
26.36	360379.5	6766668	19.478	0.751	0.047	-0.057	-0.656	-23.916	-6.064	-1.174	19.177	-0.199	0.883	24908.33	17091.53	12479.76	4611.771	12.939	0	0	0	0.35	24.7	19.199	6.539	619.336	0	0	0
26.38	360379	6766668	19.452	0.732	0.189	-0.182	-0.629	-23.916	-6.064	-1.371	19.18	0.001	0.881	24908.33	17101.74	12489.97	4611.771	12.839	0	0	0	0.35	24.711	19.201	6.613	619.829	0	0	0
26.4	360378.5	6766668	19.423	0.684	0.325	-0.298	-0.58	-23.916	-6.064	-1.567	19.183	0.189	0.832	24908.33	17113.53	12501.76	4611.771	12.741	0	0	0	0.35	24.722	19.202	6.682	620.323	0	0	0
26.42	360378	6766667	19.389	0.612	0.451	-0.402	-0.511	-23.916	-6.064	-1.763	19.187	0.357	0.742	24908.33	17126.89	12515.12	4611.771	12.643	0	0	0	0.35	24.735	19.204	6.746	620.816	0	0	0
26.44	360377.5	6766667	19.352	0.516	0.561	-0.49	-0.422	-23.916	-6.064	-1.959	19.19	0.495	0.618	24908.33	17141.83	12530.06	4611.771	12.547	0	0	0	0.35	24.75	19.206	6.806	621.31	0	0	0
26.46	360377.1	6766667	19.311	0.401	0.652	-0.559	-0.319	-23.916	-6.064	-2.155	19.193	0.599	0.468	24908.33	17158.34	12546.57	4611.771	12.451	0	0	0	0.35	24.767	19.208	6.86	621.803	0	0	0
26.48	360376.6	6766667	19.266	0.271	0.719	-0.606	-0.205	-23.916	-6.064	-2.352	19.196	0.664	0.303	24908.33	17176.43	12564.66	4611.771	12.357	0	0	0	0.35	24.784	19.209	6.909	622.297	0	0	0
26.5	360376.1	6766667	19.217	0.13	0.762	-0.629	-0.084	-23.916	-6.064	-2.548	19.198	0.691	0.132	24908.33	17196.09	12584.32	4611.771	12.263	0	0	0	0.35	24.804	19.211	6.954	622.79	0	0	0
26.52	360375.6	6766667	19.164	-0.016	0.777	-0.628	0.04	-23.916	-6.064	-2.744	19.2	0.679	-0.037	24908.33	17217.33	12605.56	4611.771	12.171	0	0	0	0.35	24.825	19.212	6.993	623.283	0	0	0
26.54	360375.2	6766667	19.107	-0.162	0.764	-0.603	0.161	-23.916	-6.064	-2.94	19.202	0.632	-0.193	24908.33	17240.14	12628.37	4611.771	12.08	0	0	0	0.35	24.847	19.214	7.028	623.777	0	0	0
26.56	360374.7	6766667	19.047	-0.302	0.725	-0.554	0.276	-23.916	-6.064	-3.136	19.204	0.555	-0.33	24908.33	17264.53	12652.76	4611.771	11.989	0	0	0	0.35	24.871	19.215	7.057	624.27	0	0	0
26.58	360374.2	6766666	18.982	-0.432	0.659	-0.485	0.38	-23.916	-6.064	-3.333	19.205	0.452	-0.441	24908.33	17290.49	12678.72	4611.771	11.9	0	0	0	0.35	24.897	19.216	7.082	624.764	0	0	0
26.6	360373.7	6766666	18.913	-0.547	0.57	-0.396	0.469	-23.916	-6.064	-3.529	19.206	0.332	-0.522	24908.33	17318.03	12706.25	4611.771	11.812	0	0	0	0.35	24.924	19.216	7.101	625.257	0	0	0
26.62	360373.2	6766666	18.841	-0.641	0.46	-0.292	0.54	-23.916	-6.064	-3.725	19.208	0.201	-0.57	24908.33	17347.14	12735.37	4611.771	11.725	0	0	0	0.35	24.952	19.217	7.116	625.751	0	0	0
26.64	360372.8	6766666	18.764	-0.713	0.335	-0.176	0.59	-23.916	-6.064	-3.921	19.209	0.067	-0.586	24908.33	17377.82	12766.05	4611.771	11.639	0	0	0	0.35	24.982	19.218	7.125	626.244	0	0	0
26.66	360372.3	6766666	18.684	-0.759	0.197	-0.054	0.618	-23.916	-6.064	-4.117	19.21	-0.062	-0.569	24908.33	17410.08	12798.31	4611.771	11.554	0	0	0	0.35	25.014	19.219	7.13	626.738	0	0	0
26.68	360371.8	6766666	18.6	-0.777	0.053	0.072	0.623	-23.916	-6.064	-4.314	19.212	-0.181	-0.523	24908.33	17443.92	12832.15	4611.771	11.47	0	0	0	0.35	25.047	19.22	7.13	627.231	0	0	0
26.7	360371.3	6766666	18.511	-0.768	-0.093	0.195	0.603	-23.916	-6.064	-4.51	19.213	-0.282	-0.452	24908.33	17479.33	12867.56	4611.771	11.387	0	0	0	0.35	25.081	19.22	7.125	627.725	0	0	0
26.72	360370.8	6766666	18.419	-0.73	-0.234	0.312	0.561	-23.916	-6.064	-4.706	19.214	-0.363	-0.361	24908.33	17516.31	12904.54	4611.771	11.305	0	0	0	0.35	25.117	19.221	7.114	628.218	0	0	0
26.74	360370.4	6766666	18.323	-0.667	-0.367	0.417	0.497	-23.916	-6.064	-4.902	19.216	-0.419	-0.256	24908.33	17554.87	12943.1	4611.771	11.224	0	0	0	0.35	25.155	19.222	7.099	628.712	0	0	0
26.76	360369.9	6766665	18.223	-0.579	-0.485	0.508	0.414	-23.916	-6.064	-5.098	19.217	-0.45	-0.144	24908.33	17595.01	12983.24	4611.771	11.138	0	0	0	0.35	25.194	19.223	7.085	629.205	0	0	0
26.78	360369.4	6766665	18.119	-0.47	-0.585	0.58	0.315	-23.916	-6.064	-5.295	19.218	-0.455	-0.031	24908.33	17636.72	13024.95	4611.771	11.034	0	0	0	0.35	25.234	19.223	7.085	629.699	0	0	0
26.8	360368.9	6766665	18.011	-0.345	-0.664	0.632	0.203	-23.916	-6.064	-5.491	19.219	-0.435	0.076	24908.33	17680	13068.23	4611.771	10.93	0	0	0	0.35	25.276	19.224	7.081	630.192	0	0	0
26.82	360368.5	6766665	17.899	-0.208	-0.717	0.66	0.084	-23.916	-6.064	-5.687	19.219	-0.394	0.174	24908.33	17724.86	13113.09	4611.771	10.826	0	0	0	0.35	25.319	19.224	7.073	630.685	0	0	0
26.84	360368	6766665	17.784	-0.063	-0.744	0.664	-0.04	-23.916	-6.064	-5.883	19.22	-0.334	0.256	24908.33	17771.29	13159.52	4611.771	10.722	0	0	0	0.35	25.364	19.225	7.062	631.179	0	0	0
26.86	360367.5	6766665	17.664	0.083	-0.743	0.644	-0.163	-23.916	-6.064	-6.079	19.221	-0.26	0.32	24908.33	17819.3	13207.53	4611.771	10.618	0	0	0	0.35	25.411	19.225	7.046	631.672	0	0	0
26.88	360367	6766665	17.541	0.226	-0.714	0.601	-0.28	-23.916	-6.064	-6.276	19.221	-0.176	0.363	24908.33	17868.89	13257.12	4611.771	10.514	0	0	0	0.35	25.458	19.226	7.027	632.166	0	0	0
26.9	360366.5	6766665	17.413	0.359	-0.658	0.535	-0.388	-23.916	-6.064	-6.472	19.222	-0.088	0.384	24908.33	17920.05	13308.27	4611.771	10.41	0	0	0	0.35	25.507	19.226	7.003	632.659	0	0	0
26.92	360366.1	6766664	17.282	0.479	-0.579	0.45	-0.482	-23.916	-6.064	-6.668	19.222	-0.001	0.383	24908.33	17972.78	13361.01	4611.771	10.306	0	0	0	0.35	25.558	19.226	6.976	633.153	0	0	0
26.94	360365.6	6766664	17.146	0.581	-0.477	0.349	-0.559	-23.916	-6.064	-6.864	19.223	0.081	0.362	24908.33	18027.09	13415.32	4611.771	10.202	0	0	0	0.35	25.61	19.227	6.945	633.646	0	0	0
26.96	360365.1	6766664	17.007	0.661	-0.358	0.234	-0.616	-23.916	-6.064	-7.06	19.224	0.154	0.323	24908.33	18082.97	13471.2	4611.771	10.098	0	0	0	0.35	25.663	19.227	6.91	634.14	0	0	0
26.98	360364.6	6766664	16.864	0.716	-0.226	0.111	-0.651	-23.916	-6.064	-7.257	19.224	0.214	0.269	24908.33	18140.43	13528.66	4611.771	9.994	0	0	0	0.35	25.718	19.227	6.87	634.633	0	0	0

27	360364.2	6766664	16.717	0.744	-0.085	-0.016	-0.663	-23.916	-6.064	-7.453	19.225	0.26	0.204	24908.33	18199.46	13587.69	4611.771	9.889	0	0	0	0.35	25.774	19.228	6.827	635.127	0	0	0
27.02	360363.7	6766664	16.566	0.744	0.059	-0.142	-0.65	-23.916	-6.064	-7.649	19.225	0.288	0.132	24908.33	18260.06	13648.29	4611.771	9.785	0	0	0	0.35	25.831	19.228	6.781	635.62	0	0	0
27.04	360363.2	6766664	16.411	0.716	0.201	-0.263	-0.615	-23.916	-6.064	-7.845	19.226	0.3	0.058	24908.33	18322.25	13710.48	4611.771	9.681	0	0	0	0.35	25.89	19.228	6.73	636.114	0	0	0
27.06	360362.7	6766664	16.252	0.661	0.335	-0.375	-0.557	-23.916	-6.064	-8.041	19.226	0.295	-0.016	24908.33	18386	13774.23	4611.771	9.577	0	0	0	0.35	25.95	19.228	6.675	636.607	0	0	0
27.08	360362.2	6766663	16.089	0.581	0.457	-0.473	-0.479	-23.916	-6.064	-8.238	19.227	0.275	-0.084	24908.33	18451.33	13839.56	4611.771	9.473	0	0	0	0.35	26.011	19.229	6.616	637.101	0	0	0
27.1	360361.8	6766663	15.923	0.48	0.563	-0.553	-0.384	-23.916	-6.064	-8.434	19.227	0.241	-0.143	24908.33	18518.24	13906.47	4611.771	9.369	0	0	0	0.35	26.074	19.229	6.554	637.594	0	0	0
27.12	360361.3	6766663	15.752	0.36	0.647	-0.613	-0.275	-23.916	-6.064	-8.63	19.227	0.197	-0.191	24908.33	18586.72	13974.95	4611.771	9.265	0	0	0	0.35	26.138	19.229	6.487	638.088	0	0	0
27.14	360360.8	6766663	15.577	0.227	0.707	-0.651	-0.157	-23.916	-6.064	-8.826	19.227	0.144	-0.227	24908.33	18656.78	14045.01	4611.771	9.161	0	0	0	0.35	26.204	19.229	6.416	638.581	0	0	0
27.16	360360.3	6766663	15.399	0.084	0.742	-0.665	-0.033	-23.916	-6.064	-9.022	19.228	0.087	-0.248	24908.33	18728.41	14116.64	4611.771	9.057	0	0	0	0.35	26.27	19.229	6.342	639.074	0	0	0
27.18	360359.8	6766663	15.216	-0.061	0.749	-0.654	0.092	-23.916	-6.064	-9.219	19.228	0.029	-0.254	24908.33	18801.61	14189.84	4611.771	8.952	0	0	0	0.35	26.339	19.23	6.265	639.568	0	0	0
27.2	360359.4	6766663	15.03	-0.205	0.728	-0.619	0.212	-23.916	-6.064	-9.415	19.228	-0.027	-0.247	24908.33	18876.39	14264.62	4611.771	8.845	0	0	0	0.35	26.408	19.23	6.186	640.061	0	0	0
27.22	360358.9	6766663	14.84	-0.342	0.68	-0.562	0.325	-23.916	-6.064	-9.611	19.228	-0.079	-0.227	24908.33	18952.75	14340.98	4611.771	8.737	0	0	0	0.35	26.478	19.23	6.103	640.555	0	0	0
27.24	360358.4	6766662	14.646	-0.466	0.607	-0.484	0.425	-23.916	-6.064	-9.807	19.229	-0.123	-0.196	24908.33	19030.68	14418.91	4611.771	8.628	0	0	0	0.35	26.55	19.23	6.017	641.048	0	0	0
27.26	360357.9	6766662	14.448	-0.573	0.511	-0.388	0.509	-23.916	-6.064	-10.003	19.229	-0.158	-0.157	24908.33	19110.18	14498.41	4611.771	8.519	0	0	0	0.35	26.623	19.23	5.928	641.542	0	0	0
27.28	360357.5	6766662	14.246	-0.66	0.397	-0.278	0.574	-23.916	-6.064	-10.2	19.229	-0.182	-0.111	24908.33	19191.26	14579.49	4611.771	8.41	0	0	0	0.35	26.698	19.23	5.836	642.035	0	0	0
27.3	360357	6766662	14.04	-0.723	0.267	-0.158	0.617	-23.916	-6.064	-10.396	19.229	-0.195	-0.062	24908.33	19273.91	14662.14	4611.771	8.3	0	0	0	0.35	26.773	19.23	5.74	642.529	0	0	0
27.32	360356.5	6766662	13.83	-0.759	0.128	-0.033	0.638	-23.916	-6.064	-10.592	19.23	-0.197	-0.013	24908.33	19358.14	14746.37	4611.771	8.189	0	0	0	0.35	26.85	19.231	5.641	643.022	0	0	0
27.34	360356	6766662	13.616	-0.767	-0.016	0.093	0.634	-23.916	-6.064	-10.788	19.23	-0.189	0.033	24908.33	19443.95	14832.18	4611.771	8.078	0	0	0	0.35	26.928	19.231	5.538	643.516	0	0	0
27.36	360355.5	6766662	13.398	-0.748	-0.16	0.216	0.607	-23.916	-6.064	-10.984	19.23	-0.171	0.076	24908.33	19531.33	14919.56	4611.771	7.966	0	0	0	0.35	27.007	19.231	5.433	644.009	0	0	0
27.38	360355.1	6766662	13.177	-0.701	-0.298	0.331	0.557	-23.916	-6.064	-11.181	19.23	-0.145	0.111	24908.33	19620.28	15008.51	4611.771	7.853	0	0	0	0.35	27.088	19.231	5.323	644.503	0	0	0
27.4	360354.6	6766662	12.951	-0.628	-0.425	0.433	0.487	-23.916	-6.064	-11.377	19.23	-0.113	0.139	24908.33	19710.81	15099.04	4611.771	7.74	0	0	0	0.35	27.169	19.231	5.211	644.996	0	0	0
27.42	360354.1	6766661	12.721	-0.533	-0.537	0.519	0.398	-23.916	-6.064	-11.573	19.23	-0.076	0.158	24908.33	19802.91	15191.14	4611.771	7.626	0	0	0	0.35	27.252	19.231	5.095	645.49	0	0	0
27.44	360353.6	6766661	12.488	-0.418	-0.629	0.586	0.294	-23.916	-6.064	-11.769	19.23	-0.038	0.167	24908.33	19896.59	15284.82	4611.771	7.512	0	0	0	0.35	27.336	19.231	4.976	645.983	0	0	0
27.46	360353.1	6766661	12.251	-0.287	-0.698	0.63	0.179	-23.916	-6.064	-11.965	19.23	0	0.166	24908.33	19991.84	15380.07	4611.771	7.397	0	0	0	0.35	27.421	19.231	4.853	646.477	0	0	0
27.48	360352.7	6766661	12.009	-0.147	-0.742	0.652	0.058	-23.916	-6.064	-12.162	19.23	0.036	0.157	24908.33	20088.67	15476.9	4611.771	7.282	0	0	0	0.35	27.507	19.231	4.727	646.97	0	0	0
27.5	360352.2	6766661	11.764	-0.001	-0.758	0.649	-0.066	-23.916	-6.064	-12.358	19.231	0.067	0.14	24908.33	20187.07	15575.3	4611.771	7.166	0	0	0	0.35	27.594	19.231	4.598	647.463	0	0	0
27.52	360351.7	6766661	11.515	0.145	-0.747	0.622	-0.187	-23.916	-6.064	-12.554	19.231	0.093	0.117	24908.33	20287.05	15675.27	4611.771	7.05	0	0	0	0.35	27.683	19.231	4.466	647.957	0	0	0
27.54	360351.2	6766661	11.262	0.285	-0.708	0.571	-0.302	-23.916	-6.064	-12.75	19.231	0.113	0.088	24908.33	20388.6	15776.83	4611.771	6.933	0	0	0	0.35	27.772	19.231	4.33	648.45	0	0	0
27.56	360350.8	6766661	11.005	0.415	-0.643	0.5	-0.406	-23.916	-6.064	-12.946	19.231	0.125	0.057	24908.33	20491.72	15879.95	4611.771	6.815	0	0	0	0.35	27.863	19.231	4.19	648.944	0	0	0
27.58	360350.3	6766660	10.744	0.529	-0.555	0.409	-0.495	-23.916	-6.064	-13.143	19.231	0.13	0.025	24908.33	20596.42	15984.65	4611.771	6.697	0	0	0	0.35	27.955	19.231	4.048	649.437	0	0	0
27.6	360349.8	6766660	10.479	0.624	-0.446	0.304	-0.566	-23.916	-6.064	-13.339	19.231	0.128	-0.007	24908.33	20702.7	16090.93	4611.771	6.603	0	0	0	0.35	28.047	19.232	3.876	649.931	0	0	0
27.62	360349.3	6766660	10.211	0.695	-0.321	0.187	-0.615	-23.916	-6.064	-13.535	19.231	0.119	-0.037	24908.33	20810.55	16198.78	4611.771	6.545	0	0	0	0.35	28.141	19.232	3.665	650.424	0	0	0
27.64	360348.8	6766660	9.938	0.741	-0.184	0.063	-0.643	-23.916	-6.064	-13.731	19.231	0.104	-0.062	24908.33	20919.98	16308.21	4611.771	6.488	0	0	0	0.35	28.236	19.232	3.45	650.918	0	0	0
27.66	360348.4	6766660	9.661	0.759	-0.041	-0.064	-0.646	-23.916	-6.064	-13.927	19.231	0.085	-0.083	24908.33	21030.98	16419.21	4611.771	6.42	0	0	0	0.353	28.332	19.232	3.241	651.411	0	0	0
27.68	360347.9	6766660	9.381	0.749	0.103	-0.189	-0.626	-23.916	-6.064	-14.124	19.231	0.062	-0.099	24908.33	21143.55	16531.78	4611.771	6.346	0	0	0	0.358	28.429	19.232	3.035	651.905	0	0	0
27.7	360347.4	6766660	9.096	0.712	0.244	-0.306	-0.583	-23.916	-6.064	-14.32	19.231	0.038	-0.108	24908.33	21257.7	16645.93	4611.771	6.272	0	0	0	0.363	28.527	19.232	2.825	652.398	0	0	0
27.72	360346.9	6766660	8.808	0.648	0.375	-0.413	-0.518	-23.916	-6.064	-14.516	19.231	0.012	-0.11	24908.33	21373.43	16761.66	4611.771	6.198	0	0	0	0.368	28.626	19.232	2.61	652.892	0	0	0
27.74	360346.5	6766659	8.516	0.56	0.493	-0.505	-0.434	-23.916	-6.064	-14.712	19.231	-0.012	-0.107	24908.33	21490.73	16878.95	4611.771	6.124	0	0	0	0.372	28.726	19.232	2.392	653.385	0	0	0
27.76	360346	6766659	8.22	0.452	0.592	-0.578	-0.335	-23.916	-6.064	-14.908	19.231	-0.034	-0.098	24908.33	21609.6	16997.83	4611.771	6.05	0	0	0	0.377	28.827	19.232	2.169	653.879	0	0	0
27.78	360345.5	6766659	7.92	0.327	0.669	-0.63	-0.222	-23.916	-6.064	-15.105	19.232	-0.053	-0.085	24908.33	21730.05	17118.28	4611.771	5.977	0	0	0	0.382	28.929	19.232	1.943	654.372	0	0	0
27.8	360345	6766659	7.615	0.189	0.721	-0.659	-0.102	-23.916	-6.064	-15.301	19.232	-0.069	-0.068	24908.33	21852.07	17240.3	4611.771	5.903	0	0	0	0.387	29.032	19.232	1.712	654.865	0	0	0
27.82	360344.5	6766659	7.329	0.038	0.746	-0.664	0.021	-22.04	-6.642	-11.106	20.88	-2.231	-0.707	21919.48	18978.01	13361.53	5616.473	5.83	12837.63	4392.135	0.291	0.977	25.558	21.011	1.499	655.351	0	0	0
27.84	360344.1	6766659	7.152	-0.132	0.738	-0.651	0.121	-18.762	-10.502	-1.878	15.409	-7.065	-0.197	17011.39	14140.94	9528.282	4612.654	5.755	35305.35	19055.52	0.316	1.026	21.583	16.953	1.397	655.801	0	0	0
27.86	360343.8	6766659	7.113	-0.289	0.697	-0.635	0.168	-18.762	-10.502	-2.074	15.578	-6.833	1.155	17011.39	14156.79	9544.141	4612.654	5.673	0	0	0.013	0.437	21.601	17.05	1.439	656.231	0	0	0
27.88	360343.4	6766658	7.07	-0.435	0.626	-0.61	0.214	-18.762	-10.502	-2.27	15.727	-6.366	2.426	17011.39	14174.23	9561.574	4612.654	5.592	0	0	0.001	0.416	21.621	17.139	1.478	656.661	0	0	0
27.9	360343	6766658	7.022	-0.566	0.53	-0.577	0.257	-18.762	-10.502	-2.466	15.859	-5.684	3.57	17011.39	14193.24	9580.583	4612.654	5.51	0	0	0	0.423	21.642	17.221	1.512	657.091	0	0	0
27.92	360342.6	6766658	6.997	-0.674	0.414	-0.534	0.3	-18.342	-9.479	2.498	15.442	-3.71	1.794	15186.02	12378.09	8846.731	3531.361	5.43	20519.24	3148.504	0.217	0.911	20.797	15.982	1.567	657.517	0.053	2.141	40.647
27.94	360342.3	6766658	7.045	-0.752	0.297	-0.475	0.347	-18.342	-9.479	2.302	15.488	-3.254	2.438	15186.02	12358.83	8827.47	3531.361	5.354	0	0	0.008	0.458	20.774	16.013	1.691	657.93	0	0	0