Master Thesis

Analysis and Evaluation of Rockfall Hazard

Aidin Eivazi Adli

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Chair of Subsurface Engineering
Department Mineral Resources Engineering
Motanuniversitaet Leoben

A-8700 LEOBEN, Erzherzog-Johann-Straße 3/III
Phone: +43/(0)3842-402-3401
Fax: +43/(0)3842-402-6602
subsurface@unileoben.ac.at

Declaration of authorship

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Ich erkläre an Eides statt, dass ich diese Arbeit selbständig verfasst, andere als die angegebenen Quellen und Hilfsmittel nicht benutzt und mich auch sonst keiner unerlaubten Hilfsmittel bedient habe.

AFFIDAVIT

I declare in lieu of oath, that I wrote this thesis and performed the associated research myself, using only literature cited in this volume.

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Datum Unterschrift

Acknowledgement

This article is reviewed based on efforts by researchers and engineers.

I want to thank my kindly wife, my parents, all teachers, professors and friends who have helped me to learn and gathering this content.

Abstract

Rockfall in open pit mines can result in serious harms damaging plants or vehicles and killing mine workers or other persons that may enter the mining area. To avoid them, cleaning up berms is one of the important works regarding operation. But this method is time-consuming and costly. The need for a cheap and fast way to protect the open pit mining area from rockfall has led to this study. Finally, four vertical profiles from Erzberg mining area and three different scenarios are analyzed with various geotechnical parameters. It is the biggest iron ore open pit mine in Central Europe. For the rockfall simulations the "RocFall" software is used. This is a statistical analysis program designed to assist with a risk assessment of rock slopes and evaluation of mitigation measures. An extensive parameter study is performed. One parameter set originates from former investigations and the other ones are selected from the "Rocscience Coefficient of Restitution" Table suggested by "RocFall" software. The outcomes of the simulations lead to a huge amount of data. After several processing steps, the required heights and energy capacities for the barriers are determined.

Zusammenfassung

Das Herabfallen loser Felsbrocken aus einer Abbauwand kann zu ernsten Schäden an Gebäuden und an Fahrzeugen, bis hin zum Tod von Arbeitern oder anderen Personen, die sich im Abbaugebiet aufhalten, führen. Um dieses Risiko zu minimieren, zählt das Beräumen der Bermen zu den wichtigsten Aufgaben während der Arbeiten. Diese Methode ist sowohl zeit- als auch kostenintensiv. Das Erfordernis mit möglichst kostengünstigen und einfachen Maßnahmen tieferliegende Etagen vor Steinschlag zu schützen, führte zu dieser Studie. Vier Profilschnitte des Abbaugebietes am Erzberg werden in drei verschiedenen Szenarien mit unterschiedlichen Parametern untersucht. Der Erzberg ist der größte Eisenerz-Tagbau in Mitteleuropa. Für die Steinschlagsimulationen wird die Software "RocFall" verwendet, ein statistisches Analyseprogramm zur Risikobewertung von Felsböschungen und zur Evaluierung entsprechender Sicherungsmaßnahmen. Eine umfangreiche Parameterstudie wird durchgeführt. Die Parameter einer Variante stammen von früheren Untersuchungen, die anderen werden der "Rocscience Coefficient of Restitution" Tabelle der Software "RocFall" entnommen. Die Ergebnisse der verschiedenen Steinschlagsimulationen ergeben große Datenmengen. Nach mehreren Entwicklungsschritten werden die erforderlichen Höhen der Barrieren und die entsprechenden Energieeinträge ermittelt.

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List of abbreviations

φ	Friction angle of the line segment
θ	Slope angle of the line segment
g	Gravity
R_N	Normal Restitution coefficient
R_T	Tangential Restitution coefficient
t	Time
V	Linear velocity
V_h	Horizontal velocity
V_v	Vertical velocity

1 Introduction

In mining areas rockfall hazards can result in serious harms and in the worst case in death of humans.

The rockfall is caused via a wedge failure along an interface of rock mass joints. Ground vibration during blasting, weathering, groundwater, snow, rainfall and the time dependent characteristics of rock contribute to failure possibility. Actually, visual inspection and cleaning is not readily accessible for all failing potentials and scaling or cleaning operations are costly.

The mining industry is well aware of the dangers of loose rock falling from the backs and walls of underground mines. In open pit mines, however, these hazards are sometimes not fully recognized.

Rockfall fences and barriers are designed to absorb energy from rolling or bouncing rocks with the goal of retaining the rock and debris.

Some advantage of rockfall barriers in open-pit mines are:

- Provide effective protection for workers, equipment, access roads, tunnel portals and buildings.
- Save mining costs.

Also in effect of increased yield by installation of flexible rockfall barriers via use of ring net barriers, there are more advantage as follow:

- Reduce the berm width.
- Increase the berm height.

The software which is used for the investigation in this thesis is RocFall from Rocscience Company.

1.1 Study Site

The rock fall simulations were performed for slopes at the Erzberg mine. “The Erzberg mine which is a large open-pit mine located in Eisenerz, Styria, in the central-western part of Austria, 60 km north-west of Graz and 260 km south-west of the capital, Vienna. The Erzberg represents the largest iron ore reserves in Austria having estimated reserves of 235 million tons of ore. The mine produces around 2,153,000 tons of iron ore/year.”[1]

“Since the beginning of mining activity about 230 million t of iron ore have been mined at the Erzberg; 200 million tons in twentieth century. There are still 140 million tons of recoverable and another 95 million tons of geological reserves left. It is the biggest iron ore open pit mine in Central Europe. Mining activities encompass the whole mountain, which rises about 700 m above the bottom of the valley up to 1400 m above sea level and covers an area of about 6,5 km^2. Mining is done in about 30 levels with a height of 24 m. Main ore minerals are siderite, ankerite and ferrous dolomite. Accessory minerals are pyrite, arsenopyrite, chalcopyrite, tetraedrite and cinnabar.

Active mining areas exhibit fresh rock surfaces of different lithologies. Abandoned mining areas comprise weathered rocks of different types covered by vegetation of different intensity and condition. Dumps and heaps consist of material of different lithological mixtures, of different grain or block size, at different slope angle. Depending on their status of use heaps and dumps show no vegetation at all or are covered by different types and intensities of vegetation. In tailing ponds fine grained material is deposited. ”[2]

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[1] http://www2.brgm.fr/mineo/alpine.htm (10 October, 2014)

[2] http://www.abenteuer-erzberg.at/en/ (19 October, 2014)

1.1.1 Geology

“The Erzberg deposit has undergone several orogenesies, two of them represent the main Alpine orogenetic cycles, namely the older Variscan orogeny and the younger Alpine orogeny.

During the Variscan orogeny there was an overlapping of two originally adjoining carbonate floes. The argillaceous schist functioned as a slipway and thus they are located between the footwall floe and the hanging wall floe. As a result, some of the intermediate schist were squeezed into the thick layers, which caused a tectonic reduplication, i.e. a partial nappe was formed. Stratigraphically, the Lower to Upper Carboniferous intermediate schist belongs to the footwall floe. The Upper Permian Werfen Layers overlie the floes and prove there by the Pre-Upper (i.e., Variscan) age of this formation.

As a result of the Alpine orogeny, whole layer sequence was trough-like deformed around a North-East sub margin axis. During this deformation numerous fault of intrusions occurred. The Christof Main fault strike a North-South and dip to East, is the dominatingfault inside the deposit. The part of the trough East of this fault was lowered about 350 meters to East. This also was the compelling geological reason for underground mining at the Erzberg. The rich ore deposits located behind the border of the open pit could only be extracted economically through underground mining. However, the underground mining was as planned at the beginning of 1986.

The steep Vordernberg vertical fault has caused a major strike-slip fault, but only in the northern area of the surface mine. There is also local fragmentation and displacement of several meters along fracture systems sub parallel to the Christof Main fault respectively in the direction of the main deformation axis. The contact zone of the Werfen layers with the ore-bearing formation is heavily disturbed and folded in some areas. In this areas the bedrock breccia is heavily slated, folded, and can barely be differentiated from calcareous schist.

The Erzberg deposit consists of carbonitic iron ore (siderite) conjoined with iron-magnesium carbonate (ankerite) in changing intensity. There is no definitive answer of the geological origins of the Erzberg. Investigation indicate, that the Erzberg's volcanic base was leached by circulating water. This iron rich hydrothermal water entered the sedimentation basin as early as during the Paleozoic period and all the lime sludge turned into iron carbonates as a result of precipitation.

The Erzberg's deposit geology has three main geological categories:

- Porphyroid bedrock (footwall).
- Ore-bearing formations (main deposit).
- Werfen breccia and Werfen schist (hanging wall, base layers of the Northern limestone Alps)." [3]

1.2 Aim and Objectives of thesis

This thesis are assessed the potential hazard and the effect of rock fall in all various states

The investigation includes the following four principal steps:

1. Definition of the boundaries and input data:
    - Different geometries (four vertical profiles of the open pit).
    - Different rock parameters (Eight different material properties, one of these parameter sets was recommended by Montanuniversitaet and the other ones were suggested by Rocscience.
    - Different states
        - Complete cleared berms without loos rocks
        - Today's condition of berms and slops with different levels of filling
        - Berms and slopes completely backfilled with fallen rock.
2. Rock fall simulation and preparation of output.
3. Analyzing and processing of data to define suitable data.
4. Determination of required barrier specification.

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[3] http://www.abenteuer-erzberg.at/en/ (19 October, 2014)

2 Literature Review

In places where are intense rockfall activities, properly designed protection systems reduce or avoid the dangers to people, vehicles and buildings. Therefore, realistic rockfall trajectories are required to determine bounce height and kinetic energy of fallen rocks. This two parameters are very important for rockfall barrier designing.

2.1 Rockfall

Rockfall occur when rocks break away from slopes exceeding the rock strength mostly along joints. The failure mechanism can be of natural or anthropogenic origin, such as:

- Heavy rainfall.
- Freeze-thaw cycles.
- Earthquake.
- Weathering.
- Pore water pressure.
- Road cuts.
- Open pit mine.

The initial velocity of the falling rock depends on the triggering cause.

Depending on topography of the slopes and berms, the movements of rocks are:

- Free fall.
- Rolling.
- Sliding.

If the falling rocks are loosened from an overhang, the rocks free falls until they impact the ground. If the boulders are originate from the top of a slope, they may either slide or roll.

Under the force of gravity, the falling rocks keep on moving by rolling or bouncing with both rotational and translational velocities and there are an enormous increase in their kinetic energies. The kinetic energy decreases during the downward movement by any contact with obstacles and damping materials such as:

- Trees.
- Surface roughness of slopes.
- Debris loose rocks.
- Reverse slopes in case of ditches.

2.1.1 Parameters for Rocfall

“The following relative parameters are briefly described:

- Angular Velocity.
- Coefficient of Normal Restitution Scaling.
- Friction Angle.
- Coefficients of Restitution.

In the calculations properties of the mass of each rock are concentrated in a point. Because of this, it is important to keep in mind that any size or shape effects have to be considered by approximations or adjustments other properties.

2.1.1.1 Angular Velocity

The angular velocity option provides a more realistic simulation of the motion. Unless there is a reason to do otherwise, the initial angular velocity for the rocks is often zero.

The engineering judgment must use to pick the value with sufficient accuracy that is applicable to the real situation, but in general, the initial value for angular velocity is fairly small and often zero. The idea is, that most of the rocks start slowly, but tumbling down the slope, they can start rotating quite quickly.

2.1.1.2 Coefficient of Normal Restitution Scaling

The concept behind scaling the normal coefficient of restitution by the velocity is that normal restitution coefficients depends on it.

2.1.1.3 Friction Angle

The friction angle is chosen based on the particle shape and the mode of movement. The input value of the friction angle is the inclination of the segment such that a rock tossed onto this segment would continue to move down the slope. In general, lower values are more conservative.

2.1.1.4 Coefficients of Restitution

The outcome of the simulation is quite sensitive to the value of coefficients of restitution.

The coefficients of restitution are normally distributed. Since the mean values of coefficients of restitution are rarely well known, selecting the standard deviations are even more difficult.

As a general rule, harder materials have higher coefficients of restitution than softer materials, and if the normal coefficient of restitution increases the tangential coefficient of restitution increase too. ''[4]

2.1.2 Definition of Terms Used in Rockfall protection Design

The following are some of the terms used in rockfall protection design:

- Catch Ditch

  A catch ditch is provided to trap the falling rock coming down the slope.

- Fall Out Areas

  A flat ground provided at the base of slopes to retard the falling rock velocity.

- Mesh or cable nets

  Mesh or cable nets are usually provided either to retard.

- Rockfall Barrier

  Barrier is usually kept the falling rock.

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[4] Roc Science: Advanced Tutorial; Article prepared for RocNews Fall 2003

2.2 Research on Rockfalls

On 1963, Arthur M. Ritchie recognized the need to understand the actual rockfall process. He noted that there is a clear need for a means of predicting the stability of material on the surface of a rock cut, and thus he states in his paper (Ritchie 1963):

"So far, these factors remain elusive and many engineers approach the problem with apathy, as though walking up to a stone wall and half-heartedly demanding that the wall give up its secrets and come under their slide rule "[5].

After that, a lot of papers have been published on this topic during the past 30 years and considerable progress has been made in explaining rockfall behavior. Most of the work was done in an attempt to keep falling rock reaching transportation corridors like roads and railway lines.

Research to understand and analyze rockfall behavior has been approached in two ways:

- Empirical methods.
- Computer simulations.

2.2.1 Empirical Methods

Empirical methods are including:

- In-situ tests
  In-situ tests are investigate on the actual behavior of rockfalls and the falling rocks tracking at the practical condition on site.
- Scaled test
  This is an alternative method to define the behavior of falling rocks to compare the result with in-situ tests.

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[5] Ritchie A.M: Highways Research Researched Record: Evaluation of rockfalls and its control

2.2.2 Computer Simulation

Until 1989, the empirical methods (in-situ tests) were used to define the behavior of falling rocks. They are costly and risky methods. In addition to these methods, the computer of falling rocks has become a cheap and efficient tool. Computer simulations have emerged as a preferable analysis method for rockfall. Because it is efficient for simulation of both random and repeatable behavior of falling rocks.

It is used to get the distribution of important parameters of falling rocks required for the design of rockfall protection structures such as:

- Kinetic energy.
- Bounce height.
- Velocity.
- Trajectories.

One of the key inputs for computer simulation of rockfall are the coefficients of restitution. They are very important to define precise and realistic outputs. These coefficients are usually determined from the suggested values by some authors. Those suggestion base on the results of in-situ and scaled tests. For example:

- Richards, 1988.
- Pfeiffer and Bowen, 1989.
- Azzoni et al., 1995.
- Elliott, 1992.
- Hungr and Evans, 1984.
- Advanced Tutorial; Article prepared for RocNews Fall 2003; RocScience.

2.2.3 Conclusion

Regarding the research work done by various authors using different methods (in-situ tests, and computer simulation) and the comparison of them (methods and results), show that the restitution coefficients are very sensitive and have big influence on the result especially with computer simulation methods.

2.3 Rockfall Protection

They are structures to protect areas below slopes from rockfall. There are several different types of protection structures:

- Mesh or cable nets.
- Catchment areas.
- Barriers and fences.
- Rockfall protection embankment.

These devices allow rocks to fall but prevent them from causing any damage to structures or person. Hence, the requirements on protection structures are:

- Stop falling rocks.
- Control trajectories.
- Reduce kinetic energy.
- Provide catchment.

2.3.1 Mesh or Cable Nets

Mesh and cable nets control rockfall and erosion in two ways:

- They hold the rocks behind the mesh/net.
- They direct them safety to a catchment area at the bottom of the slope.

They can be unsecured (attached to anchors at the top of the slope) or secured at both top and bottom.

2.3.2 Catchment areas

Catchment areas dissipate rockfall energy and collect rocks and debris that have detached from a slope. They are areas of flat or rising ground. Catchment areas control risk of falling rock by:

- Ditches - along the foot of a slope.
- Hybrid ditches, which combine a ditch with a barrier (typically a wall or an embankment).

2.3.3 Barriers and fences

The effect of barriers and fences are:

- Stop falling rocks.
- Absorb kinetic energy of the rocks.
- Block their trajectories.
- Detain them before hazards occur.

There are several types of barriers fallowing as:

- Earth barriers.
- Concrete barriers.
- Structural walls.
- Flexible barriers.
- Attenuators.

They can also be used in combination with ditches when there is a limitation of ditch space.

3 RocFall Software

“RocFall is a statistical analysis program designed to assist with a risk assessment of rock slopes and to evaluate protection measures. Rocfall determines energy, velocity and bounce height envelopes for the entire slope and the location of rock endpoints. The distribution of all results can be graphed along the slope profiles. The output of this software is comprehensive and complete.

3.1 Software Assumptions

a) Each rock is modelled as a particle. The size of the rocks are not considered by this software because the particle are thought of point still. Each rock has a weight. The weight is constant throughout the simulation. The consequence is that the rocks cannot break or split during the simulation.

b) No consideration to the air resistance.

c) The slopes are modelled as one continuous group of straight line segments, connected end to end.’’ [6]

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[6] Roc Science: Advanced Tutorial; Article prepared for RocNews Fall 2003

4 Methodology

Given the purpose of this thesis the simulation are performed with different rock parameters, rock weights, and vertical profiles.

4.1 Profiles and states

Four decisive profiles were determined and three different conditions states were examined.

- Cleared berms (All berms and slops are cleared and without debris and rubbles).
- Present situation (Some parts of berms and slopes are filled with rocks).
- Filled berms (assumed all berms will be filled with a repose angle of 35 degree slope).

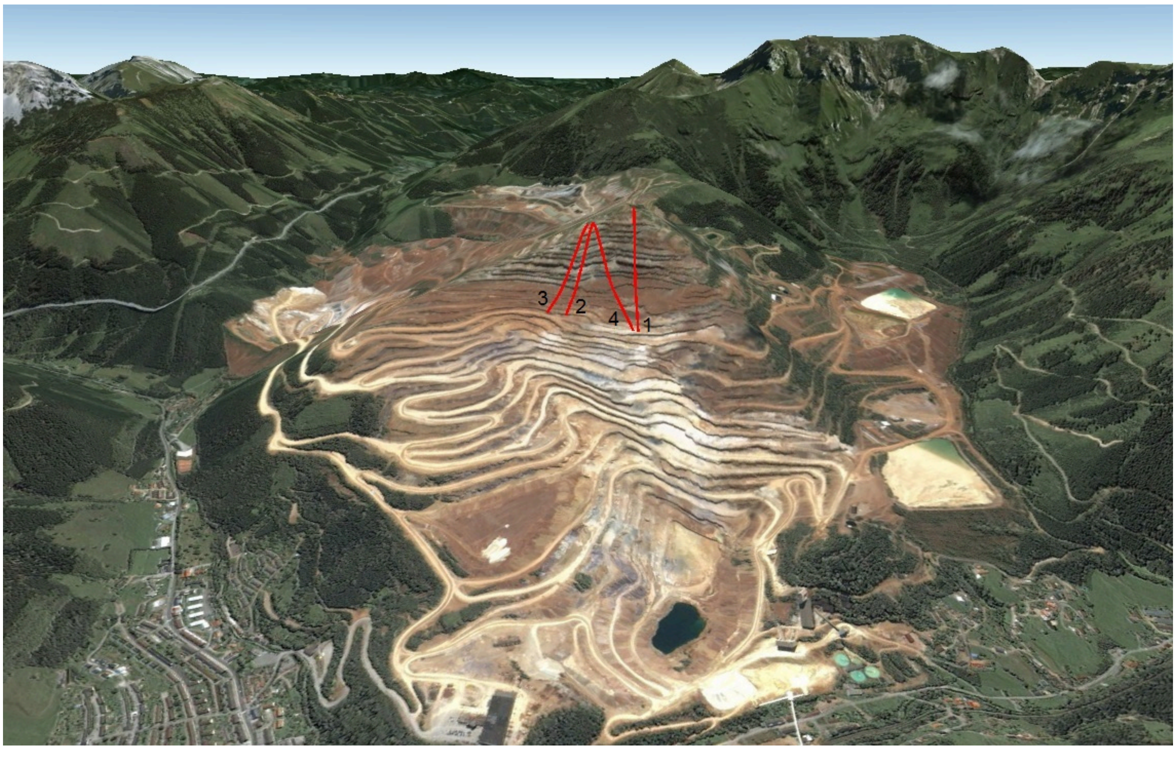

Figure 1: Location of Profiles

4.2 Rock Parameters

Eight different material properties were selected for berms and slops. One of these parameters sets was prepared by Montanuniversitaet and the other ones were selected from Rocscience Coefficient of Restitution Table. This table shows the Coefficient of Normal Restitution (R_n) and the Coefficient of Tangential Restitution (R_t) from seven projects in the world. After graphs analyze was done on the input data, the Montan University data verified. For the simulations, six different sizes of rocks were specified, which are inputted in rockfall weights:

- 0.25 ton.
- 0.50 ton.
- 1.00 ton.
- 5.00 ton.
- 10.00 ton.
- 15.00 ton.

The density of rock is assumed with 2.6 $^{\mathrm{g}}/_{\mathrm{cm}^3}$.

10,000 is the maximum number of falling rocks that can be chosen in the RocFall software. In all calculations and simulation, the maximum number was set.

4.3 Simulation

According to the four profiles and the three states, twelve models were prepared with the eight parameter sets for the rocks. 96 simulations were performed to determine the crucial profile and states.

4.4 Outputs

Each simulation has 14 different graphs as output. Five types of graphs are important to decide height and requirement of barriers as follow:

- Horizontal location of fallen rocks end-points.
- Bounce height envelope.
- Total kinetic energy envelope.
- Total Kinetic energy on barrier.
- Y-Impact (vertical) location on barrier.

4.5 Result and Conclusion

Results are analyzed and compared to define the requirement.

5 Determine primary Input Data

5.1 Profiles

Four profiles from Erzberg mine created by the mining map and aerial laser mapping data. From each profile, three new profiles were generated. The barriers are installed for all profiles on level Rothballer 1166 m above sea level (refer to section 4.1).

5.2 Velocities of Falling Rocks

For rockfall simulation, two major types of rock velocities are considered:

- Angular velocity.
- Linear velocity

The linear velocity is split into two components:

- Horizontal velocity
- Vertical velocity.

The angular velocity option provides a more realistic simulation of the motion of rocks. The initial angular velocity in all simulations was set zero.

To determine values of the linear velocities of all rocks were calculated after 0.5 seconds.

$V_v = g \times t + v_0$ (5.1)

$V = V_v \div sin\ \theta$ (5.2)

$V_h = V \times cos\ \theta$ (5.3)

Where:

V : Linear velocity ($^{m}/_{s}$)

V_v : Vertical velocity ($^{m}/_{s}$)

V_h : Horizontal velocity ($^{m}/_{s}$)

v_0 : Initial velocity (0.0 $^{m}/_{s}$)

g : Gravity (9.81 $^{m}/_{s^2}$)

t : Time (0.5 s)

θ : Angle of slope (°)

The angle of slopes of each profile was defined one by one. Then the vertical velocities and horizontal velocities were calculated and allocated for all weight classes.

5.3 Slopes and Berms Characteristics

5.3.1 Friction Angle (φ)

“The friction angle is chosen based on the particle shape and the mode of movement. In general, lower values are more conservative.

With the same material of rocks on the slopes and berms, the friction angle will be set different by depending on whether the rocks are all spherical shaped rocks, or if they are flat slabs. If the rocks are long flat slabs, the mode of movement will be sliding, and the values to enter are higher. If the rocks are all spherical, then mode of movement will tend to be rolling, rather than sliding, and the value is much lower.

There is another option available in the Project Settings dialog of RocFall that affect the friction angle. The option “Calculate friction angle from R_T” provides a method to define the friction angle by the coefficient of tangential restitution.

$$\varphi = \frac{(1 - R_T)}{R_T}$$

This option has the advantage of correlating the friction angle and the coefficient of tangential restitution, and reduces the required number of parameters. This method is used in all simulations.”[7]

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[7] Roc Science: Advanced Tutorial; Article prepared for RocNews Fall 2003

5.3.2 Coefficient of Normal Restitution (R_N) and Tangential Restitution (R_T)

The selection of proper coefficients of restitution is important, because the outcome is quite sensitive to the values applied.

The Rocscience Coefficient of Restitution Table includes the data which are available from Rocscience. The values of coefficients of restitution are generally difficult to specify.

Table 1 shows the original Rocscience Coefficient of Restitution Table. Unsuitable Data are left out. This table was modified in two step:

- First modification:
  Some data about falling rocks and standard deviations are not included in the original and according to other sources, this data were complemented on the Table 2.
- Second modification:
  Several coefficient of restitution are specified as minimum and maximum values. Those values were replaced by mean values, because for the simulation normal distribution are used (Table 3).

No.	Material			R_N				R_T			
				mean	std- dev	min	max	mean	std- dev	min	max
1	Glenwood Canyon, Colorado, USA	Hard surface paving	Berm			0.370	0.420			0.870	0.920
		Bedrock or boulders with little soil or vegetation	Slope			0.330	0.370			0.830	0.870
		Talus with little vegetation	Falling Rock			0.300	0.330			0.830	0.830
2	Limestone quarry in England	Limestone face	Berm	0.315	0.064			0.712	0.116		
		Partially vegetated limestone scree	Slope	0.303	0.080			0.615	0.170		
			Falling Rock								
3	Atrani, Campania, Southern Italy	Dolomitic limestone boulders on rocky surfaces and on talus desposits	Berm	0.200				0.530			
		Remolded pyroclastic from the terraces situated at the base of the cliff	Slope	0.100				0.200			
		Impacts on detritus of the fans present at the foot of a rock cliff	Falling Rock	0.000				0.240			
4	Italcementi works at Castellammare di Stabia, area of Atrani	Bedrock	Berm	0.500				0.950			
		Bedrock covered by large blocks	Slope	0.350				0.850			
		Debris formed by uniform distributed elements	Falling Rock	0.300				0.700			
5	Colorado, USA	Smooth hard surfaces and paving	Berm			0.370	0.420			0.870	0.920
		Most bedrock and boulder fields	Slope			0.330	0.370			0.820	0.850
		Talus and firm soil slopes	Falling Rock			0.300	0.330			0.800	0.830
6	Mountain road, near Bolzano, South Tyrol, Italy	Clean Hard Bedrock	Berm	0.530	0.040			0.990	0.040		
		Bedrock outkrop	Slope	0.350	0.040			0.850	0.040		
		Talus cover	Falling Rock	0.320	0.040			0.820	0.040		
7	170m deep open pit, Tasmania, Australia (overall pit angle between 55 and 65 degrees)	Clean Hard Bedrock	Berm	0.530	0.040			0.990	0.040		
		Bedrock outcrop	Slope	0.350	0.040			0.850	0.040		
			Falling Rock								

Table 1: Rocscience Coefficient of Restitution Table[8]

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[6] Rocscience Coefficient of Restitution Table

No.	Material			R_N				R_T			
				mean	std- dev	min	max	mean	std- dev	min	max
1	Glenwood Canyon, Colorado, USA	Hard surface paving	Berm			0.370	0.420			0.870	0.920
		Bedrock or boulders with little soil or vegetation	Slope			0.330	0.370			0.830	0.870
		Talus with little vegetation	Falling Rock			0.300	0.330			0.830	0.830
2	Limestone quarry in England	Limestone face	Berm	0.315	0.064			0.712	0.116		
		Partially vegetated limestone scree	Slope	0.303	0.080			0.615	0.170		
			Falling Rock	0.250	0.050			0.500	0.150		
3	Atrani, Campania, Southern Italy	Dolomitic limestone boulders on rocky surfaces and on talus desposits	Berm	0.200	0.040			0.530	0.100		
		Remolded pyroclastic from the terraces situated at the base of the cliff	Slope	0.100	0.020			0.200	0.040		
		Impacts on detritus of the fans present at the foot of a rock cliff	Falling Rock	0.000	0.010			0.240	0.050		
4	Italcementi works at Castellammare di Stabia, area of Atrani	Bedrock	Berm	0.500	0.100			0.950	0.190		
		Bedrock covered by large blocks	Slope	0.350	0.070			0.850	0.170		
		Debris formed by uniform distributed elements	Falling Rock	0.300	0.060			0.700	0.150		
5	Colorado, USA	Smooth hard surfaces and paving	Berm			0.370	0.420			0.870	0.920
		Most bedrock and boulder fields	Slope			0.330	0.370			0.820	0.850
		Talus and firm soil slopes	Falling Rock			0.300	0.330			0.800	0.830
6	Mountain road, near Bolzano, South Tyrol, Italy	Clean Hard Bedrock	Berm	0.530	0.040			0.990	0.040		
		Bedrock outkrop	Slope	0.350	0.040			0.850	0.040		
		Talus cover	Falling Rock	0.320	0.040			0.820	0.040		
7	170m deep open pit, Tasmania, Australia (overall pit angle between 55 and 65 degrees)	Clean Hard Bedrock	Berm	0.530	0.040			0.990	0.040		
		Bedrock outcrop	Slope	0.350	0.040			0.850	0.040		
			Falling Rock	0.250	0.040			0.700	0.040		
* Red colored are assumed values											

Table 2: Coefficient of Restitution (First modification)

No.	**Material**			R_N				R_T			
				mean	**std- dev**	**min**	**max**	**mean**	**std- dev**	**min**	**max**
1	Glenwood Canyon, Colorado, USA	Hard surface paving	Berm	0.109	0.039	0.000	0.000	0.621	0.000	0.000	0.000
		Bedrock or boulders with little soil or vegetation	Slope	0.720	5.800	0.000	0.000	0.621	0.000	0.000	0.000
		Talus with little vegetation	Falling Rock	0.315	0.064	0.000	0.000	0.712	0.116	0.000	0.000
2	Limestone quarry in England	Limestone face	Berm	0.395	0.025	0.000	0.000	0.895	0.025	0.000	0.000
		Partially vegetated limestone scree	Slope	0.350	0.020	0.000	0.000	0.850	0.020	0.000	0.000
			Falling Rock	0.315	0.015	0.000	0.000	0.830	0.000	0.000	0.000
3	Atrani, Campania, Southern Italy	Dolomitic limestone boulders on rocky surfaces and on talus desposits	Berm	0.315	0.064	0.000	0.000	0.712	0.116	0.000	0.000
		Remolded pyroclastic from the terraces situated at the base of the cliff	Slope	0.303	0.080	0.000	0.000	0.615	0.170	0.000	0.000
		Impacts on detritus of the fans present at the foot of a rock cliff	Falling Rock	0.250	0.050	0.000	0.000	0.500	0.150	0.000	0.000
4	Italcementi works at Castellammare di Stabia, area of Atrani	Bedrock	Berm	0.200	0.040	0.000	0.000	0.530	0.100	0.000	0.000
		Bedrock covered by large blocks	Slope	0.100	0.020	0.000	0.000	0.200	0.040	0.000	0.000
		Debris formed by uniform distributed elements	Falling Rock	0.000	0.010	0.000	0.000	0.240	0.050	0.000	0.000
5	Colorado, USA	Smooth hard surfaces and paving	Berm	0.500	0.100	0.000	0.000	0.950	0.190	0.000	0.000
		Most bedrock and boulder fields	Slope	0.350	0.070	0.000	0.000	0.850	0.170	0.000	0.000
		Talus and firm soil slopes	Falling Rock	0.300	0.060	0.000	0.000	0.700	0.150	0.000	0.000
6	Mountain road, near Bolzano, South Tyrol, Italy	Clean Hard Bedrock	Berm	0.395	0.025	0.000	0.000	0.895	0.025	0.000	0.000
		Bedrock outkrop	Slope	0.350	0.020	0.000	0.000	0.835	0.015	0.000	0.000
		Talus cover	Falling Rock	0.315	0.015	0.000	0.000	0.815	0.015	0.000	0.000
7	170m deep open pit, Tasmania, Australia (overall pit angle between 55 and 65 degrees)	Clean Hard Bedrock	Berm	0.530	0.040	0.000	0.000	0.990	0.040	0.000	0.000
		Bedrock outcrop	Slope	0.350	0.040	0.000	0.000	0.850	0.040	0.000	0.000
			Falling Rock	0.320	0.040	0.000	0.000	0.820	0.040	0.000	0.000
* Red colored are assumed values											

Table 3: Coefficient of Restitution (Second modification)

In Table 4 the data determined by Montanuniversitaet are listed.

Table 5 show the comparison of the Coefficient of Restitution for eight different projects. According to this table, Figure 2 and Figure 3 were created.

Material		R_N		R_T	
		mean	**std- dev**	**mean**	**std- dev**
Erzberg	Berm	0.109	0.039	0.621	0.000
	Slope	0.720	5.800	0.621	0.000
	Falling Rock	0.315	0.064	0.712	0.116

Table 4: Montanuniversitaet Coefficient of Restitution

No.	**Material**	R_N			R_T		
		Berm	Slope	Falling Rock	Berm	Slope	Falling Rock
1	Erzberg	0.109	0.720	0.315	0.621	0.621	0.712
2	Glenwood Canyon, Colorado, USA	0.395	0.350	0.315	0.895	0.850	0.830
3	Limestone quarry in England	0.315	0.303	0.250	0.712	0.615	0.500
4	Atrani, Campania, Southern Italy	0.200	0.100	0.000	0.530	0.200	0.240
5	Italcementi works at Castellammare di Stabia, area of Atrani	0.500	0.350	0.300	0.950	0.850	0.700
6	Colorado, USA	0.395	0.350	0.315	0.895	0.835	0.815
7	Mountain road, near Bolzano, South Tyrol, Italy	0.530	0.350	0.320	0.990	0.850	0.820
8	170m deep open pit, Tasmania, Australia (overall pit angle between 55 and 65 degrees)	0.530	0.350	0.250	0.990	0.850	0.700

Table 5: Coefficient of Restitution of different projects

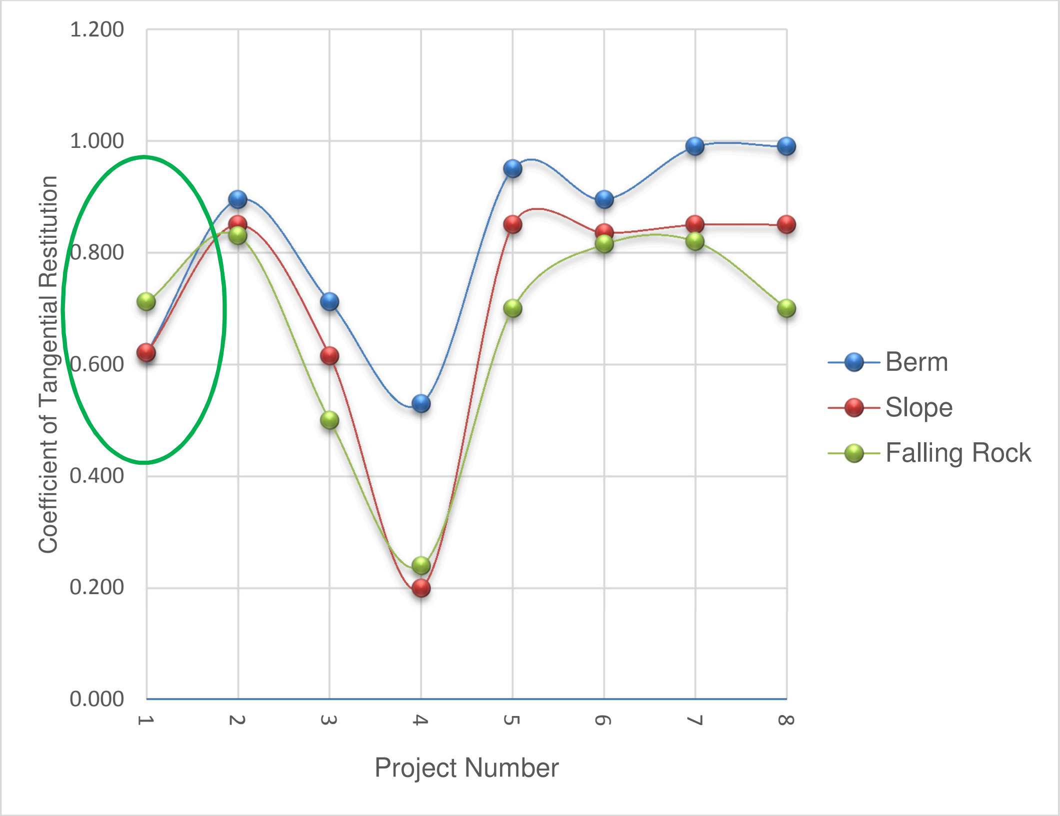

Figure 2: Coefficient of Tangential Restitution (R_T)

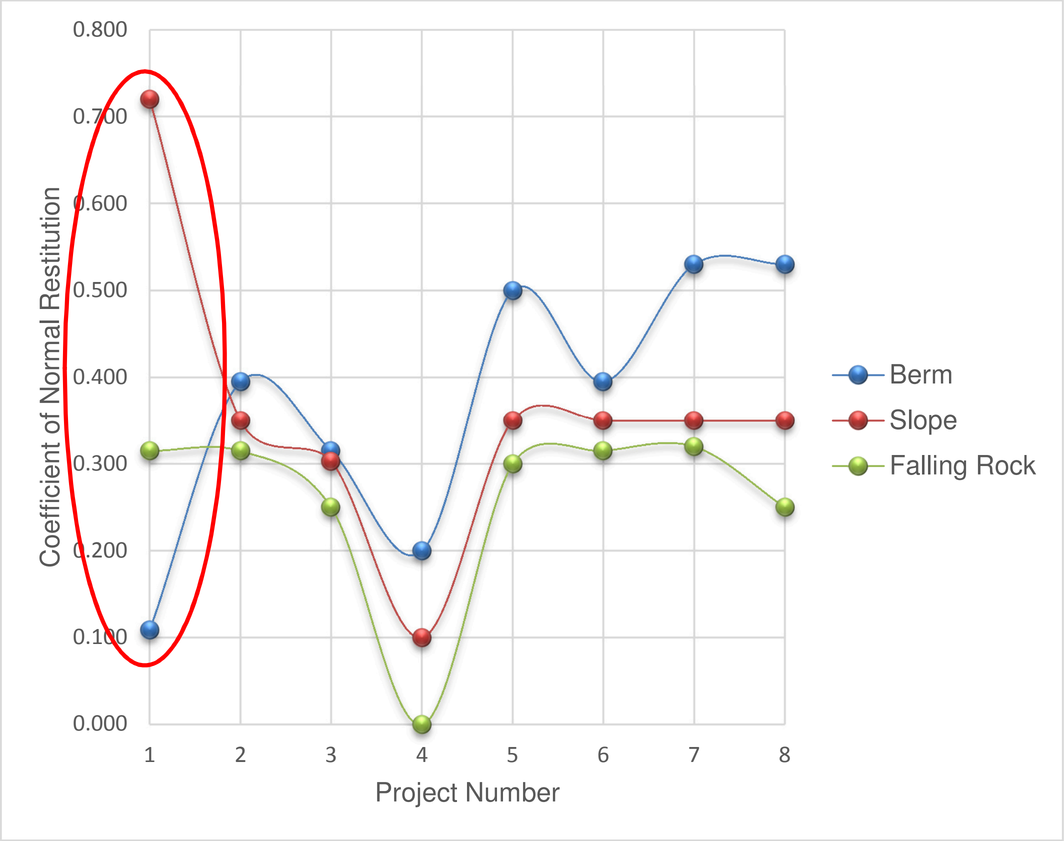

Figure 3: Coefficient of Normal Restitution (R_N)

Figure 3 shows a large range of values of the Coefficient of Normal Restitution determined by Montanuniversitaet. This deviation is not plausible. Thus, this data set was revised on Table 7 (marked red). Of doing this, the relation coefficient between Normal and Tangential Restitution was calculated for other projects. Average of them were used to revise Normal Restitution of Montanuniversitaet data set (Table 7).

No.	Material	Berm			Slope			Falling Rock		
		R_T	R_N	R_N/R_T	R_T	R_N	R_N/R_T	R_T	R_N	R_N/R_T
1	Glenwood Canyon, Colorado, USA	0.895	0.395	0.441	0.850	0.350	0.412	0.830	0.315	0.380
2	Limestone quarry in England	0.712	0.315	0.442	0.615	0.303	0.493	0.500	0.250	0.500
3	Atrani, Campania, Southern Italy	0.530	0.200	0.377	0.200	0.100	0.500	0.240	0.000	0.000
4	Italcementi works at Castellammare di Stabia, area of Atrani	0.950	0.500	0.526	0.850	0.350	0.412	0.700	0.300	0.429
5	Colorado, USA	0.895	0.395	0.441	0.835	0.350	0.419	0.815	0.315	0.387
6	Mountain road, near Bolzano, South Tyrol, Italy	0.990	0.530	0.535	0.850	0.350	0.412	0.820	0.320	0.390
7	170m deep open pit, Tasmania, Australia (overall pit angle between 55 and 65 degrees)	0.990	0.530	0.535	0.850	0.350	0.412	0.700	0.250	0.357
Average				0.471			0.437			0.349

Table 6: Relation Coefficient between Rocscience ($\boldsymbol{R_T}$) and ($\boldsymbol{R_N}$)

Material		R_N		R_T	
		mean	**std- dev**	**mean**	**std- dev**
Erzberg	Berm	0.300	0.100	0.621	0.000
	Slope	0.270	0.100	0.621	0.000
	Falling Rock	0.250	0.100	0.712	0.116
* Red colored are modified values					

Table 7: Modified Coefficient of Normal Restitution

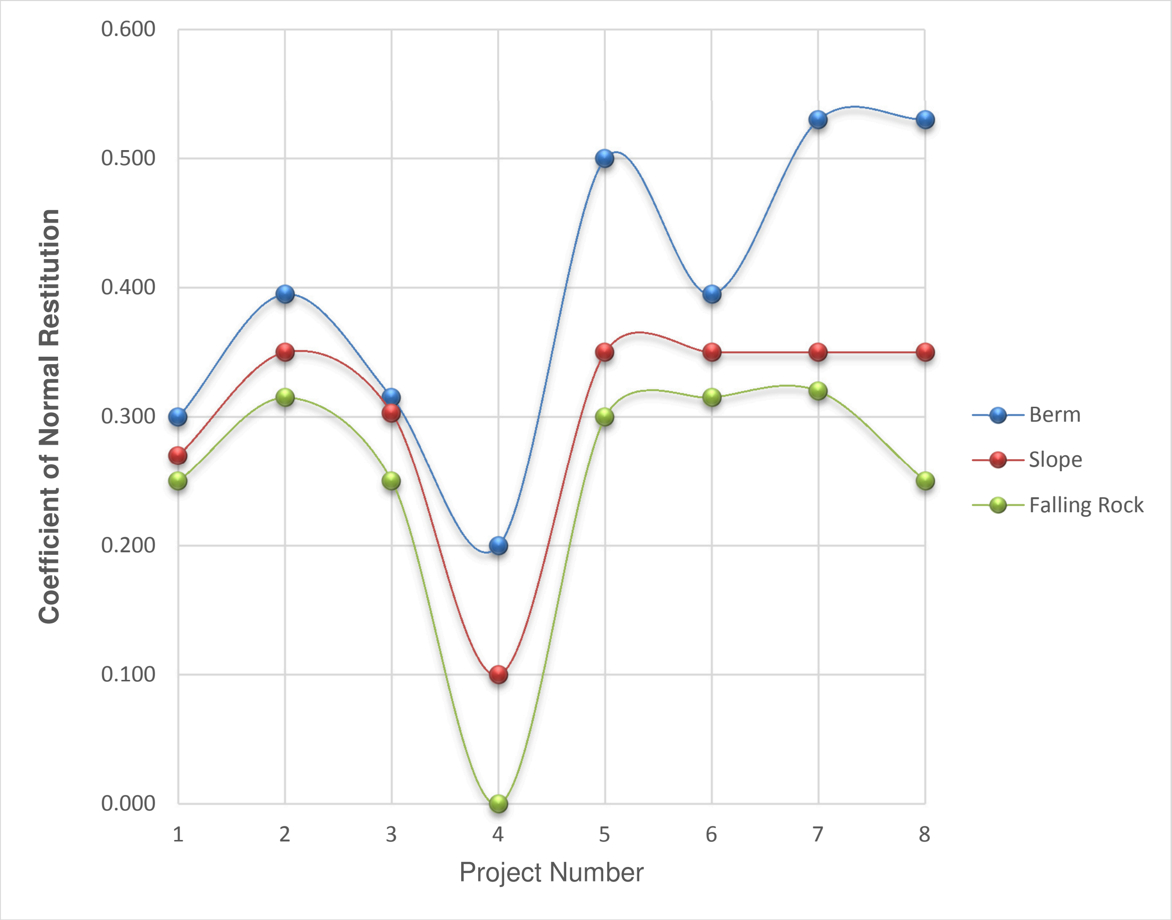

Figure 4: Modified Coefficient of Normal Restitution

Table **8** summarizes the projects for the rockfall simulations including an assessment:

- Number 2 and 6: No comparable situation in appropriate.
- Number 4, 5 and 7: Tolerable.
- Number 1, 3 and 8: Suitable.

Finally all of them were used in simulations and the results are compared.

No.	Project Name	Situation
1	Erzberg	Erzberg open pit mine in Austria
2	Glenwood Canyon	Forest area in Colorado, USA
3	Limestone quarry	Open pit mine in England
4	Atrani, Campania	Residential area and shrubbery area in Southern Italy
5	Italcementi works at Castellammare di Stabia, area of Atrani	Residential area and shrubbery area in Italy
6	Colorado	Forest area in USA
7	Mountain road	Residential area and shrubbery area with trees near Bolzano, South Tyrol, Italy
8	170m deep open pit,(overall pit angle between 55 and 65 degrees)	Open pit mine area in Australia

🟩	**Suitable**
🟨	**Tolerable**
🟥	**Inappropriate**

Table 8: Condition Table of Available Projects

No.	Available Projects			R_N		R_T	
				mean	std- dev	mean	std- dev
1	Erzberg		Berm	0.300	0.100	0.621	0.000
			Slope	0.270	0.100	0.621	0.000
			Falling Rock	0.250	0.100	0.712	0.116
2	Glenwood Canyon	Hard surface paving	Berm	0.395	0.025	0.895	0.025
		Bedrock or boulders with little soil or vegetation	Slope	0.350	0.020	0.850	0.020
		Talus with little vegetation	Falling Rock	0.315	0.015	0.830	0.000
3	Limestone quarry	Limestone face	Berm	0.315	0.064	0.712	0.116
		Partially vegetated limestone scree	Slope	0.303	0.080	0.615	0.170
			Falling Rock	0.250	0.050	0.500	0.150
4	Atrani, Campania	Dolomitic limestone boulders on rocky surfaces and on talus desposits	Berm	0.200	0.040	0.530	0.100
		Remolded pyroclastic from the terraces situated at the base of the cliff	Slope	0.100	0.020	0.200	0.040
		Impacts on detritus of the fans present at the foot of a rock cliff	Falling Rock	0.000	0.010	0.240	0.050
5	Italcementi works at Castellammare di Stabia, area of Atrani	Bedrock	Berm	0.500	0.100	0.950	0.190
		Bedrock covered by large blocks	Slope	0.350	0.070	0.850	0.170
		Debris formed by uniform distributed elements	Falling Rock	0.300	0.060	0.700	0.150
6	Colorado, USA	Smooth hard surfaces and paving	Berm	0.395	0.025	0.895	0.025
		Most bedrock and boulder fields	Slope	0.350	0.020	0.835	0.015
		Talus and firm soil slopes	Falling Rock	0.315	0.015	0.815	0.015
7	Mountain road	Clean Hard Bedrock	Berm	0.530	0.040	0.990	0.040
		Bedrock outkrop	Slope	0.350	0.040	0.850	0.040
		Talus cover	Falling Rock	0.320	0.040	0.820	0.040
8	170m deep open pit,(overall pit angle between 55 and 65 degrees)	Clean Hard Bedrock	Berm	0.530	0.040	0.990	0.040
		Bedrock outcrop	Slope	0.350	0.040	0.850	0.040
			Falling Rock	0.250	0.040	0.700	0.040

Table 9: Applied Coefficient of Tangential and Normal Restitution

6 Analysis

RocFall provides the results in JPG and Excel format.

All results for all profiles were evaluated and summarized.

6.1 Raw Data

All executed simulation result in 1344 graphs in total, due to the large number of result graphs the data had be classified and summarized.

“The major goals are followed by Envelope Graphs:

- Coordination Graphs (Maximum bounce height and horizontal end-points).
- Kinetic Energy of falling rocks.
- Velocity of falling rocks.

If the barrier is chosen on the falling rocks tracks, some limitation will appear (if rocks hit barriers, they stop falling).

The key elements designing rock fences and barriers are bounce height and velocity. The bounce height and velocity are determined using RocFall and used along with rock properties to determine the appropriate fence barrier height and strength"[9].

These graph names are:

- Rock end-points coordination.
- Bounce height.
- Y (vertical) impact locations on the barrier.
- Total Kinetic energy.
- Translational Kinetic Energy.
- Rotational Kinetic Energy.
- Translational Velocity.
- Rotational Velocity.

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[9] Rocscience Inc.: RocFall, Risk Analysis of Falling Rocks on Steep Slopes: User’s Guide: 1998 - 2002

6.2 Data Processing

Five types of graphs were selected on the basis of the following criteria:

- Aim of investigation.
- Define maximum kinetic energy loaded on the barrier.
- Define maximum Y (vertical) impact locations on the barrier.
- Define horizontal location of rock end-points.

These five types of graphs are 480 graphs in total:

- X (horizontal) impact locations on the barrier.
- Y (vertical) impact locations on the barrier.
- Bounce height envelope of falling rocks.
- Total Kinetic Energy that strike the barrier.
- Total kinetic energy envelope of falling rocks.

6.2.1 Bounce Height Graph

“The horizontal axis of the Bounce Height graphs are the x-coordinate of the slopes and the vertical axis are the maximum bounce heights are plotted.

This type of graph has two advantages:

- Define the maximum height of bounce.
- Outline the risk of rockfall along the profile due to bounce height"[10].

Annex III, Figure 5 to Figure 16 show these graphs. To summarize the results, eight different berm and slope parameter sets are combined together.

6.2.2 Total Kinetic Energy Envelope of Falling Rocks

“The horizontal axis of the Total Kinetic Energy graph are the x-coordinate of the slopes and the vertical axis are the maximum total kinetic energy at that location"[10]. The total kinetic energy includes the rotational and translational energy. This type of graphs define the maximum total kinetic energy.

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[10] Rocscience Inc.: RocFall, Risk Analysis of Falling Rocks on Steep Slopes: User’s Guide: 1998 - 2002

Annex IV, Figure 17 to Figure 28 show bounce height. To summarize the results, eight different berm and slope parameter sets are combined together.

6.2.3 X (Horizontal) Impact Locations

"RocFall can plot a histogram of the horizontal location of endpoints. The horizontal axis of the Horizontal Location of Rock End-points graph is the x-coordinate of the slope and the vertical axis is the number of rocks that ended in the bin at that location. This type of graphs determine the number of rock will be impact to barrier"[11].

Annex V, Figure 29 to Figure 40 show the graphs of horizontal impact locations and the number of rockfall impact on the barrier.

6.2.4 Y (Vertical) Impact Locations on the Barrier

"RocFall also provides a histogram of the vertical location of rockfall impacts on the barrier. The horizontal axis are the Y-coordinate of the impact from the barrier benchmark and the vertical axis are the number of rocks.

This graph has two advantages:

- Define the number of rock will be impact to barrier.
- Define the maximum Height of impact on barrier"[11].

The volume of data is huge in these graphs. Therefore some boundaries were defined and graphs were simplified.

In the new graph format, three major groups (scenarios) are presented:

- Probable (Scenario A).
- Between Probable and Improbable (Scenario B).
- Improbable (Scenario C).

For these graphs, the percentage of rocks hitting the barrier are plotted on the horizontal axis and the height of impact on the vertical axis.

Annex VI, Figure 41 to Figure 52 show vertical impact location graphs.

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[11] Rocscience Inc.: RocFall, Risk Analysis of Falling Rocks on Steep Slopes: User's Guide: 1998 - 2002

6.2.5 Total Kinetic Energy on Barrier

RocFall has output such as histogram of the Total Kinetic Energy of rockfall impacts on the barrier. The total kinetic energy in this graph includes rotational energy and translational energy. This graph determines the maximum kinetic energy on barrier.

According to volume of data, some boundaries were defined and graphs were simplified such as 6.2.4 scenarios.

The percentage of rocks hitting the barrier are plotted on the horizontal axis and the kinetic energy on the vertical axis (Annex VII, Figure 53 to Figure 64).

6.3 Results

According to the graphs, the results of the suitable condition projects are more comprehensive and they are matching with this research condition. Also they cover maximum critical values. These three project are:

- Erzberg open pit mine in Austria.
- Limestone quarry, open pit mine area in England.
- 170 m deep open pit, (overall pit angle between 55 and 65 degrees), open pit mine are in Tasmania, Australia.

Therefore, these three items were focused and collected three projects result in Table 10 and Table 11.

Project	**Profile**	**State**	**Bounce Height**		**Total Kinetic Energy Envelope**		**X (Horizontal) Impact Locations**	
			Horizontal Distance From First Point of Profile (m)	**Maximum Amount (m)**	**Horizontal Distance From First Point of Profile (m)**	**Maximum Amount (KJ)**	**Horizontal Distance From First Point of Profile (m)**	**Maximum Amount (Rocks)**
Erzberg open pit mine in Austria	I	Cleared Berms	**X = 227**	**63.5**	X = 162	8946	X = 198	842
		Present Situation	X = 227	44.5	X = 260	10643	X = 62	1468
		Filled Berms	X = 260	20.4	**X = 253**	**11457**	**X = 334**	**3351**
	II	Cleared Berms	X = 160	38.0	X = 169	11157	X = 215	1231
		Present Situation	X = 203	25.9	X = 213	8909	X = 220	1133
		Filled Berms	X = 155	17.1	X = 213	11160	X = 269	2324
	III	Cleared Berms	X = 53	21.6	X = 159	6937	X = 84	829
		Present Situation	X = 149	25.5	X = 159	7513	X = 209	1077
		Filled Berms	X = 178	15.5	X = 259	11096	X = 267	2427
	IV	Cleared Berms	X = 148	25.5	X = 160	6771	X = 277	936
		Present Situation	X = 148	27.8	X = 205	8186	X = 214	1361
		Filled Berms	X = 143	14.5	X = 148	9045	X = 231	290
170 m deep open pit (open pit mine are in Australia)	I	Cleared Berms	**X = 227**	**92.9**	X = 273	21273	X = 380	8039
		Present Situation	X = 279	76.1	**X = 312**	**23508**	X = 341	4571
		Filled Berms	X = 260	17.2	X = 234	8018	X = 380	9593
	II	Cleared Berms	X = 213	59.4	X = 242	15849	X = 263	9848
		Present Situation	X = 242	60.7	X = 194	15728	X = 259	4013
		Filled Berms	X = 155	16.6	X = 169	8533	X = 278	9949
	III	Cleared Berms	X = 235	70.2	X = 187	15494	X = 257	9765
		Present Situation	X = 235	58.9	X = 231	17821	X = 262	4426
		Filled Berms	X = 149	15.6	X = 159	7864	**X = 276**	**9964**
	IV	Cleared Berms	X = 205	63.7	X = 205	16267	X = 294	9490
		Present Situation	X = 154	50.9	X = 200	16341	X = 288	3993
		Filled Berms	X = 143	16.1	X = 194	7759	X = 294	8973
Limestone quarry (open pit mine in England)	I	Cleared Berms	**X = 227**	**43.9**	X = 162	9126	X = 205	1093
		Present Situation	X = 227	33.0	X = 260	10607	**X = 62**	**1456**
		Filled Berms	X = 260	17.3	X = 188	6129	X = 88	573
	II	Cleared Berms	X = 160	37.5	**X = 189**	**11138**	X = 215	952
		Present Situation	X = 189	21.5	X = 213	8086	X = 220	1228
		Filled Berms	X = 155	16.4	X = 261	7347	X = 17	1119
	III	Cleared Berms	X = 154	25.0	X = 159	6433	X = 214	909
		Present Situation	X = 149	31.2	X = 163	7617	X = 214	889
		Filled Berms	X = 178	15.6	X = 259	6047	X = 267	386
	IV	Cleared Berms	X = 148	26.6	X = 154	7139	X = 60	1009
		Present Situation	X = 148	25.0	X = 205	10580	X = 128	989
		Filled Berms	X = 143	12.0	X = 188	4505	X = 288	1065

Table 10: Bounce Height-Total Kinetic Energy-Horizontal Impact Locations

Project	Profile	State	Y (Vertical) Impact Locations on the Barrier (m)		Total Kinetic Energy on the Barrier (KJ)	
			Hitting Rockfalls Percentage		Hitting Rockfalls Percentage	
			90%	95%	90%	95%
Erzberg open pit mine in Austria	I	Cleared Berms	0.0		0	
		Present Situation	4.4		357	
		Filled Berms	0.0		0	
	II	Cleared Berms	0.9	3.7	18	
		Present Situation	**6.5**		382	
		Filled Berms	1.3		907	2061
	III	Cleared Berms	5.0		497	
		Present Situation	0.0		0	
		Filled Berms	1.7		**1054**	**2675**
	IV	Cleared Berms	0.0		0	
		Present Situation	0.8		109	
		Filled Berms	1.8		361	
170 m deep open pit (open pit mine are in Australia)	I	Cleared Berms	1,8	9.8	963	2889
		Present Situation	9.2	**33.6**	**3005**	
		Filled Berms	1.9		1597	
	II	Cleared Berms	12.1	26.0	1699	**5774**
		Present Situation	6.5	11.7	2113	
		Filled Berms	4.1		2537	
	III	Cleared Berms	**12.1**	26.1	1569	5335
		Present Situation	5.7	20.8	2252	
		Filled Berms	1.7	5.2	2568	
	IV	Cleared Berms	7.0		2148	
		Present Situation	5.2	8.2	1471	
		Filled Berms	1.8		1534	
Limestone quarry (open pit mine in England)	I	Cleared Berms	1.8		390	
		Present Situation	0.9		42	
		Filled Berms	1.9		168	
	II	Cleared Berms	0.9		89	
		Present Situation	1.3		417	
		Filled Berms	1.3		983	
	III	Cleared Berms	1.5		398	840
		Present Situation	0.7		237	
		Filled Berms	1.7		**515**	**1954**
	IV	Cleared Berms	**2.5**		157	
		Present Situation	0.8		155	465
		Filled Berms	1.8		171	804

Table 11: Vertical Impact Locations and Total Kinetic Energy on the Barrier

7 Conclusion

These result were calculated by different material properties. To define reliable results and increase the accuracy of them, Back Analyses method is useful. According to 2.2.1, some in situ tests must be done and the material properties will be calibrated by empirical test results.

According to result, risks assessment have great roll to select criteria values for barrier design. In this regard there are four points of view (Table 12).

Point of view	Point of view	Hitting Rockfalls Percentage	Y (Vertical) Impact Locations on the Barrier (m)	Total Kinetic Energy on the Barrier (KJ)
I	Erzberg open pit mine in Austria	90%	6.52	1054
II		95%	6.52	2675
III	170 m deep open pit (open pit mine are in Australia)	90%	12.07	3005
IV		95%	33.60	5774

Table 12: Results Pints of View

Choosing one of these numbers need precise risk assessment and evaluate for project demands, limitation and criteria. Some of these items are:

- Environmental criteria's.
- Construction limitations.
- Demands of client.
- Cost.

Also, these values are calculation values and need design safety factors to use for design. There are different guide lines and codes to define safety factors to design the barriers.

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Annex I: Vertical Impact Location on Barrier

Profile I - Cleared Berms - Y (Vertical) Impact Locations on the Barrier											
No.	Location	Total Number of Rocks	Probable (Scenario A)			Between Probable and Improbable (Scenario B)			Improbable (Scenario C)		
			Number of Rocks	Height Above Slope [m]	Percentage of Rocks	Number of Rocks	Height Above Slope [m]	Percentage of Rocks	Number of Rocks	Height Above Slope [m]	Percentage of Rocks
1	Erzberg	0									
2	Glenwood Canyon, USA	194	194	1.6	100.0%						
3	Limestone quarry in England	6	6	1.8	100.0%						
4	Atrani, Campania, Southern Italy	0									
5	Italcementi works at Castellammare di Stabia	5350	5071	1.8	94.8%	220	1.8 ~ 13.8	4.11%	59	13.8 ~ 62.1	1.1%
6	Colorado, USA	157	157	1.8	100.0%						
7	Mountain road, near Bolzano, Soth Tyrol, Italy	10783	9930	1.8	92.1%	662	1.8 ~ 9.8	6.14%	191	9.8 ~ 38.0	1.8%
8	170m deep open pit, Australia	10812	9916	1.8	91.7%	693	1.8 ~ 9.8	6.41%	203	9.8 ~ 42.0	1.9%

Table 13: Profile I - Cleared Berms - Y (Vertical) Impact Locations on the Barrier

Profile II - Cleared Berms - Y (Vertical) Impact Locations on the Barrier											
No.	Location	Total Number of Rocks	Probable (Scenario A)			Between Probable and Improbable (Scenario B)			Improbable (Scenario C)		
			Number of Rocks	Height Above Slope [m]	Percentage of Rocks	Number of Rocks	Height Above Slope [m]	Percentage of Rocks	Number of Rocks	Height Above Slope [m]	Percentage of Rocks
1	Erzberg	68	62	0.9	91.2%	5	0.9 ~ 3.7	7.4%	1	3.7 ~ 6.5	1.5%
2	Glenwood Canyon, USA	6440	6101	0.9	94.7%	328	0.9 ~ 3.7	5.09%	11	3.7 ~ 6.5	0.2%
3	Limestone quarry in England	145	143	0.9	98.6%	2	0.9 ~ 3.7	1.38%	0	3.7 ~ 3.7	0.0%
4	Atrani, Campania, Southern Italy	3	3	0.9	100.0%						
5	Italcementi works at Castellammare di Stabia	8120	7694	11.0	94.8%	304	11.0 ~ 20.1	3.74%	122	20.1 ~ 61.2	1.5%
6	Colorado, USA	6357	6036	0.9	95.0%	316	0.9 ~ 3.7	4.97%	5	3.7 ~ 9.3	0.1%
7	Mountain road, near Bolzano, Soth Tyrol, Italy	9842	9146	12.1	92.9%	581	12.1 ~ 26.0	5.90%	115	26.0 ~ 42.7	1.2%
8	170m deep open pit, Australia	9834	9117	12.1	92.7%	591	12.1 ~ 26.0	6.01%	126	26.0 ~ 42.7	1.3%

Table 14: Profile II - Cleared Berms - Y (Vertical) Impact Locations on the Barrier

Profile III - Cleared Berms - Y (Vertical) Impact Locations on the Barrier

No.	Location	Total Number of Rocks	Probable (Scenario A)			Between Probable and Improbable (Scenario B)			Improbable (Scenario C)		
			Number of Rocks	Height Above Slope [m]	Percentage of Rocks	Number of Rocks	Height Above Slope [m]	Percentage of Rocks	Number of Rocks	Height Above Slope [m]	Percentage of Rocks
1	Erzberg	327	288	1.5	88.1%	37	1.5 ~ 5.0	11.3%	2	5.0 ~ 8.6	0.6%
2	Glenwood Canyon, USA	5211	5005	1.5	96.0%	206	1.5 ~ 5.0	3.95%			
3	Limestone quarry in England	548	534	1.5	97.4%	14	1.5 ~ 5.0	2.55%			
4	Atrani, Campania, Southern Italy	17	17	1.5	100.0%						
5	Italcementi works at Castellammare di Stabia	7737	7287	12.1	94.2%	323	12.1 ~ 22.6	4.17%	127	22.6 ~ 50.8	1.6%
6	Colorado, USA	5066	4899	1.5	96.7%	167	1.5 ~ 5.0	3.30%			
7	Mountain road, near Bolzano, Soth Tyrol, Italy	9749	8951	12.1	91.8%	665	12.1 ~ 26.2	6.82%	133	26.2 ~ 43.8	1.4%
8	170m deep open pit, Australia	9757	8963	12.1	91.9%	662	12.1 ~ 26.1	6.78%	132	26.1 ~ 47.3	1.4%

Table 15: Profile III - Cleared Berms - Y (Vertical) Impact Locations on the Barrier

Profile IV - Cleared Berms - Y (Vertical) Impact Locations on the Barrier

No.	Location	Total Number of Rocks	Probable (Scenario A)			Between Probable and Improbable (Scenario B)			Improbable (Scenario C)		
			Number of Rocks	Height Above Slope [m]	Percentage of Rocks	Number of Rocks	Height Above Slope [m]	Percentage of Rocks	Number of Rocks	Height Above Slope [m]	Percentage of Rocks
1	Erzberg	0									
2	Glenwood Canyon, USA	803	803	2.5	100.0%						
3	Limestone quarry in England	17	17	2.5	100.0%						
4	Atrani, Campania, Southern Italy	0									
5	Italcementi works at Castellammare di Stabia	5331	4939	2.5	92.6%	297	2.5 ~ 7.0	5.57%	95	7.0 ~ 42.9	1.8%
6	Colorado, USA	905	905	2.5	100.0%						
7	Mountain road, near Bolzano, Soth Tyrol, Italy	9503	9250	7.0	97.3%	181	7.0 ~ 11.5	1.90%	72	11.5 ~ 29.4	0.8%
8	170m deep open pit, Australia	9485	9246	7.0	97.5%	166	7.0 ~ 11.5	1.75%	73	11.5 ~ 33.9	0.8%

Table 16: Profile IV - Cleared Berms - Y (Vertical) Impact Locations on the Barrier

Profile I - Present Situation - Y (Vertical) Impact Locations on the Barrier											
No.	Location	Total Number of Rocks	Probable (Scenario A)			Between Probable and Improbable (Scenario B)			Improbable (Scenario C)		
			Number of Rocks	Height Above Slope [m]	Percentage of Rocks	Number of Rocks	Height Above Slope [m]	Percentage of Rocks	Number of Rocks	Height Above Slope [m]	Percentage of Rocks
1	Erzberg	3	3	4.4	100.0%						
2	Glenwood Canyon, USA	4167	3938	2.8	94.5%	208	2.8 ~ 6.4	4.99%	21	6.4 ~ 10.1	0.5%
3	Limestone quarry in England	4	4	0.9	100.0%						
4	Atrani, Campania, Southern Italy	0									
5	Italcementi works at Castellammare di Stabia	419	381	2.7	90.9%	19	2.7 ~ 8.4	4.53%	19	8.4 ~ 31.1	4.5%
6	Colorado, USA	3577	3541	3.1	99.0%	35	3.1 ~ 9.2	0.98%	1	9.2 ~ 15.3	0.0%
7	Mountain road, near Bolzano, Soth Tyrol, Italy	7445	6979	15.3	93.7%	377	15.3 ~ 33.6	5.06%	89	33.6 ~ 70.2	1.2%
8	170m deep open pit, Australia	4513	4176	9.2	92.5%	287	9.2 ~ 33.6	6.36%	50	33.6 ~ 64.1	1.1%

Table 17: **Profile I - Present Situation - Y (Vertical) Impact Locations on the Barrier**

Profile II - Present Situation - Y (Vertical) Impact Locations on the Barrier											
No.	Location	Total Number of Rocks	Probable (Scenario A)			Between Probable and Improbable (Scenario B)			Improbable (Scenario C)		
			Number of Rocks	Height Above Slope [m]	Percentage of Rocks	Number of Rocks	Height Above Slope [m]	Percentage of Rocks	Number of Rocks	Height Above Slope [m]	Percentage of Rocks
1	Erzberg	9	9	6.5	100.0%						
2	Glenwood Canyon, USA	5037	4814	1.3	95.6%	216	1.3 ~ 3.9	4.29%	7	3.9 ~ 6.5	0.1%
3	Limestone quarry in England	2	2	1.3	100.0%						
4	Atrani, Campania, Southern Italy	0									
5	Italcementi works at Castellammare di Stabia	2546	2289	6.5	89.9%	228	6.5 ~ 19.6	8.96%	29	19.6 ~ 48.3	1.1%
6	Colorado, USA	5686	5425	1.3	95.4%	251	1.3 ~ 3.9	4.41%	10	3.9 ~ 9.1	0.2%
7	Mountain road, near Bolzano, Soth Tyrol, Italy	7918	7250	9.1	91.6%	558	9.1 ~ 22.2	7.05%	110	22.2 ~ 35.2	1.4%
8	170m deep open pit, Australia	3952	3627	6.5	91.8%	267	6.5 ~ 11.7	6.76%	58	11.7 ~ 48.3	1.5%

Table 18: **Profile II - Present Situation - Y (Vertical) Impact Locations on the Barrier**

Profile III - Present Situation - Y (Vertical) Impact Locations on the Barrier											
No.	**Location**	Total Number of Rocks	**Probable (Scenario A)**			**Between Probable and Improbable (Scenario B)**			**Improbable (Scenario C)**		
			Number of Rocks	Height Above Slope [m]	Percentage of Rocks	Number of Rocks	Height Above Slope [m]	Percentage of Rocks	Number of Rocks	Height Above Slope [m]	Percentage of Rocks
1	Erzberg	0									
2	Glenwood Canyon, USA	6428	6271	0.7	97.6%	81	0.7 ~ 2.0	1.26%	76	2.0 ~ 8.7	1.2%
3	Limestone quarry in England	16	16	0.7	100.0%						
4	Atrani, Campania, Southern Italy	0									
5	Italcementi works at Castellammare di Stabia	2988	2777	6.0	92.9%	183	6.0 ~ 17.9	6.12%	28	17.9 ~ 49.7	0.9%
6	Colorado, USA	6127	6028	0.7	98.4%	91	0.7 ~ 4.7	1.49%	8	4.7 ~ 7.4	0.1%
7	Mountain road, near Bolzano, Soth Tyrol, Italy	6968	6659	9.5	95.6%	232	9.5 ~ 22.1	3.33%	77	22.1 ~ 47.3	1.1%
8	170m deep open pit, Australia	4426	4136	5.7	93.4%	243	5.7 ~ 20.8	5.49%	47	20.8 ~ 51.0	1.1%

Table 19: Profile III - Present Situation - Y (Vertical) Impact Locations on the Barrier

Profile IV - Present Situation - Y (Vertical) Impact Locations on the Barrier											
No.	**Location**	Total Number of Rocks	**Probable (Scenario A)**			**Between Probable and Improbable (Scenario B)**			**Improbable (Scenario C)**		
			Number of Rocks	Height Above Slope [m]	Percentage of Rocks	Number of Rocks	Height Above Slope [m]	Percentage of Rocks	Number of Rocks	Height Above Slope [m]	Percentage of Rocks
1	Erzberg	7	7	0.8	100.0%						
2	Glenwood Canyon, USA	4642	4139	0.8	89.2%	490	0.8 ~ 3.7	10.56%	13	3.7 ~ 5.2	0.3%
3	Limestone quarry in England	40	39	0.8	97.5%	1	0.8 ~ 2.2	2.50%			
4	Atrani, Campania, Southern Italy	0									
5	Italcementi works at Castellammare di Stabia	5477	5088	3.2	92.9%	355	3.2 ~ 9.5	6.48%	34	9.5 ~ 28.4	0.6%
6	Colorado, USA	4196	3822	0.8	91.1%	369	0.8 ~ 3.7	8.79%	5	3.7 ~ 5.2	0.1%
7	Mountain road, near Bolzano, Soth Tyrol, Italy	7179	6650	6.7	92.6%	435	6.7 ~ 11.2	6.06%	94	11.2 ~ 20.1	1.3%
8	170m deep open pit, Australia	3993	3703	5.2	92.7%	241	5.2 ~ 8.2	6.04%	49	8.2 ~ 21.6	1.2%

Table 20: Profile IV - Present Situation - Y (Vertical) Impact Locations on the Barrier

Profile I - Filled Berms - Y (Vertical) Impact Locations on the Barrier

No.	Location	Total Number of Rocks	Probable (Scenario A)			Between Probable and Improbable (Scenario B)			Improbable (Scenario C)		
			Number of Rocks	Height Above Slope [m]	Percentage of Rocks	Number of Rocks	Height Above Slope [m]	Percentage of Rocks	Number of Rocks	Height Above Slope [m]	Percentage of Rocks
1	Erzberg	0									
2	Glenwood Canyon, USA	9168	9167	1.9	100.0%	1	1.9 ~ 0.0	0.01%			
3	Limestone quarry in England	5	5	1.9	100.0%						
4	Atrani, Campania, Southern Italy	0									
5	Italcementi works at Castellammare di Stabia	3991	3983	1.9	99.8%	7	1.9 ~ 9.5	0.18%	1	9.5 ~ 13.2	0.0%
6	Colorado, USA	8661	8661	1.9	100.0%						
7	Mountain road, near Bolzano, Soth Tyrol, Italy	11772	11696	1.9	99.4%	74	1.9 ~ 9.5	0.63%	2	9.5 ~ 17.0	0.0%
8	170m deep open pit, Australia	10015	10015	1.9	100.0%						

Table 21: Profile I - Filled Berms - Y (Vertical) Impact Locations on the Barrier

Profile II - Filled Berms - Y (Vertical) Impact Locations on the Barrier

No.	Location	Total Number of Rocks	Probable (Scenario A)			Between Probable and Improbable (Scenario B)			Improbable (Scenario C)		
			Number of Rocks	Height Above Slope [m]	Percentage of Rocks	Number of Rocks	Height Above Slope [m]	Percentage of Rocks	Number of Rocks	Height Above Slope [m]	Percentage of Rocks
1	Erzberg	1803	1741	1.3	96.6%	59	1.3 ~ 4.0	3.3%	3	4.0 ~ 6.7	0.2%
2	Glenwood Canyon, USA	9867	8473	1.3	85.9%	1364	1.3 ~ 4.0	13.82%	30	4.0 ~ 6.7	0.3%
3	Limestone quarry in England	154	153	1.3	99.4%	1	1.3 ~ 4.0	0.65%			
4	Atrani, Campania, Southern Italy	0									
5	Italcementi works at Castellammare di Stabia	5588	4495	1.3	80.4%	1077	1.3 ~ 6.7	19.27%	16	6.7 ~ 14.7	0.3%
6	Colorado, USA	9858	8707	1.3	88.3%	1131	1.3 ~ 4.0	11.47%	20	4.0 ~ 6.7	0.2%
7	Mountain road, near Bolzano, Soth Tyrol, Italy	9997	9559	4.0	95.6%	427	4.0 ~ 6.7	4.27%	11	6.7 ~ 12.1	0.1%
8	170m deep open pit, Australia	9948	9890	4.0	99.4%	56	4.0 ~ 6.7	0.56%	2	6.7 ~ 9.4	0.0%

Table 22: Profile II - Filled Berms - Y (Vertical) Impact Locations on the Barrier

No.	Location	Total Number of Rocks	Probable (Scenario A)			Between Probable and Improbable (Scenario B)			Improbable (Scenario C)		
			Number of Rocks	Height Above Slope [m]	Percentage of Rocks	Number of Rocks	Height Above Slope [m]	Percentage of Rocks	Number of Rocks	Height Above Slope [m]	Percentage of Rocks
1	Erzberg	1539	1507	1.7	97.9%	32	1.7 ~ 5.2	2.1%			
2	Glenwood Canyon, USA	9769	9106	1.7	93.2%	661	1.7 ~ 5.2	6.77%	2	5.2 ~ 8.7	0.0%
3	Limestone quarry in England	166	166	1.7	100.0%						
4	Atrani, Campania, Southern Italy	0									
5	Italcementi works at Castellammare di Stabia	5725	4998	1.7	87.3%	663	1.7 ~ 5.2	11.58%	64	5.2 ~ 12.1	1.1%
6	Colorado, USA	9730	9192	1.7	94.5%	537	1.7 ~ 5.2	5.52%	1	5.2 ~ 8.7	0.0%
7	Mountain road, near Bolzano, Soth Tyrol, Italy	9993	9905	5.2	99.1%	86	5.2 ~ 8.7	0.86%	2	8.7 ~ 12.1	0.0%
8	170m deep open pit, Australia	9954	9337	1.7	93.8%	610	1.7 ~ 5.2	6.13%	7	5.2 ~ 8.7	0.1%

Table 23: Profile III - Filled Berms - Y (Vertical) Impact Locations on the Barrier

Profile IV - Filled Berms - Y (Vertical) Impact Locations on the Barrier

No.	Location	Total Number of Rocks	Probable (Scenario A)			Between Probable and Improbable (Scenario B)			Improbable (Scenario C)		
			Number of Rocks	Height Above Slope [m]	Percentage of Rocks	Number of Rocks	Height Above Slope [m]	Percentage of Rocks	Number of Rocks	Height Above Slope [m]	Percentage of Rocks
1	Erzberg	38	38	1.8	100.0%						
2	Glenwood Canyon, USA	8556	8555	1.8	100.0%	1	1.8 ~ 5.5				
3	Limestone quarry in England	115	115	1.8	100.0%						
4	Atrani, Campania, Southern Italy	0									
5	Italcementi works at Castellammare di Stabia	5414	5378	1.8	99.3%	28	1.8 ~ 5.5	0.52%	8	5.5 ~ 12.8	0.1%
6	Colorado, USA	10421	10405	1.8	99.8%	14	1.8 ~ 5.5	0.13%	2	5.5 ~ 9.1	0.0%
7	Mountain road, near Bolzano, Soth Tyrol, Italy	12371	11422	1.8	92.3%	887	1.8 ~ 9.1	7.17%	62	9.1 ~ 16.4	0.5%
8	170m deep open pit, Australia	11432	11394	1.8	99.7%	38	1.8 ~ 5.5				

Table 24: Profile IV - Filled Berms - Y (Vertical) Impact Locations on the Barrier

Annex II: Total Kinetic Energy on Barrier

Profile I - Cleared Berms - Total Kinetic Energy on the Barrier

No.	Location	Total Number of Rocks	Probable (Scenario A)			Between Probable and Improbable (Scenario B)			Improbable (Scenario C)		
			Number of Rocks	Total Kinetic Energy [KJ]	Percentage of Rocks	Number of Rocks	Total Kinetic Energy [KJ]	Percentage of Rocks	Number of Rocks	Total Kinetic Energy [KJ]	Percentage of Rocks
1	Erzberg	0									
2	Glenwood Canyon, USA	194	189	469	97.4%	5	469 ~ 813	2.58%			
3	Limestone quarry in England	6	4	40	66.7%	1	40 ~ 133	16.67%	1	133 ~ 390	16.7%
4	Atrani, Campania, Southern Italy	0									
5	Italcementi works at Castellammare di Stabia	5350	5098	725	95.3%	222	725 ~ 2660	4.15%	30	2660 ~ 7980	0.6%
6	Colorado, USA	157	124	195	79.0%	26	195 ~ 472	16.56%	7	472 ~ 915	4.5%
7	Mountain road, near Bolzano, Soth Tyrol, Italy	10783	9426	603	87.4%	1321	603 ~ 3414	12.25%	36	3414 ~ 6627	0.3%
8	170m deep open pit, Australia	10812	10181	963	94.2%	558	963 ~ 2889	5.16%	73	2889 ~ 10595	0.7%

Table 25: Profile I - Cleared Berms - Total Kinetic Energy on Barrier

Profile II - Cleared Berms - Total Kinetic Energy on the Barrier

No.	Location	Total Number of Rocks	Probable (Scenario A)			Between Probable and Improbable (Scenario B)			Improbable (Scenario C)		
			Number of Rocks	Total Kinetic Energy [KJ]	Percentage of Rocks	Number of Rocks	Total Kinetic Energy [KJ]	Percentage of Rocks	Number of Rocks	Total Kinetic Energy [KJ]	Percentage of Rocks
1	Erzberg	68	66	18	97.1%	2	18 ~ 196	2.9%			
2	Glenwood Canyon, USA	6440	6301	750	97.8%	127	750 ~ 1650	1.97%	12	1650 ~ 4949	0.2%
3	Limestone quarry in England	145	140	89	96.6%	3	89 ~ 130	2.07%	2	130 ~ 225	1.4%
4	Atrani, Campania, Southern Italy	3	3	12	100.0%						
5	Italcementi works at Castellammare di Stabia	8120	7673	1460	94.5%	379	1460 ~ 4963	4.67%	68	4963 ~ 9633	0.8%
6	Colorado, USA	6357	6271	823	98.6%	74	823 ~ 1809	1.16%	12	1809 ~ 5427	0.2%
7	Mountain road, near Bolzano, Soth Tyrol, Italy	9842	8557	1258	86.9%	1144	1258 ~ 5450	11.62%	141	5450 ~ 13833	1.4%
8	170m deep open pit, Australia	9834	8816	1699	89.6%	857	1699 ~ 5774	8.71%	161	5774 ~ 11208	1.6%

Table 26: Profile II - Cleared Berms - Total Kinetic Energy on Barrier

Profile III - Cleared Berms - Total Kinetic Energy on the Barrier

No.	Location	Total Number of Rocks	Probable (Scenario A)			Between Probable and Improbable (Scenario B)			Improbable (Scenario C)		
			Number of Rocks	Total Kinetic Energy [KJ]	Percentage of Rocks	Number of Rocks	Total Kinetic Energy [KJ]	Percentage of Rocks	Number of Rocks	Total Kinetic Energy [KJ]	Percentage of Rocks
1	Erzberg	327	233	131	71.3%	78	131 ~ 497	23.9%	16	497 ~ 862	4.9%
2	Glenwood Canyon, USA	5211	4989	510	95.7%	218	510 ~ 1527	4.18%	4	1527 ~ 5598	0.1%
3	Limestone quarry in England	548	494	398	90.1%	48	398 ~ 840	8.76%	6	840 ~ 1459	1.1%
4	Atrani, Campania, Southern Italy	17	14	219	82.4%	3	219 ~ 481	17.65%			
5	Italcementi works at Castellammare di Stabia	7737	7291	1053	94.2%	382	1053 ~ 4560	4.94%	64	4560 ~ 11575	0.8%
6	Colorado, USA	5066	4769	444	94.1%	279	444 ~ 1036	5.51%	18	1036 ~ 4880	0.4%
7	Mountain road, near Bolzano, Soth Tyrol, Italy	9749	9001	1724	92.3%	693	1724 ~ 5860	7.11%	55	5860 ~ 11374	0.6%
8	170m deep open pit, Australia	9757	8909	1569	91.3%	749	1569 ~ 5335	7.68%	99	5335 ~ 10355	1.0%

Table 27: Profile III - Cleared Berms - Total Kinetic Energy on Barrier

Profile IV - Cleared Berms - Total Kinetic Energy on the Barrier

No.	Location	Total Number of Rocks	Probable (Scenario A)			Between Probable and Improbable (Scenario B)			Improbable (Scenario C)		
			Number of Rocks	Total Kinetic Energy [KJ]	Percentage of Rocks	Number of Rocks	Total Kinetic Energy [KJ]	Percentage of Rocks	Number of Rocks	Total Kinetic Energy [KJ]	Percentage of Rocks
1	Erzberg	0									
2	Glenwood Canyon, USA	803	694	205	86.4%	77	205 ~ 387	9.59%	32	387 ~ 750	4.0%
3	Limestone quarry in England	17	14	53	82.4%	3	53 ~ 157	17.65%			
4	Atrani, Campania, Southern Italy	0									
5	Italcementi works at Castellammare di Stabia	5331	5108	863	95.8%	212	863 ~ 2587	3.98%	11	2587 ~ 5690	0.2%
6	Colorado, USA	905	800	258	88.4%	95	258 ~ 491	10.50%	10	491 ~ 771	1.1%
7	Mountain road, near Bolzano, Soth Tyrol, Italy	9503	9368	1657	98.6%	115	1657 ~ 4023	1.21%	20	4023 ~ 7809	0.2%
8	170m deep open pit, Australia	9485	9407	2148	99.2%	68	2148 ~ 5010	0.72%	10	5010 ~ 7873	0.1%

Table 28: Profile IV - Cleared Berms - Total Kinetic Energy on Barrier

Profile I - Present Situation - Total Kinetic Energy on the Barrier											
No.	Location	Total Number of Rocks	Probable (Scenario A)			Between Probable and Improbable (Scenario B)			Improbable (Scenario C)		
			Number of Rocks	Total Kinetic Energy [KJ]	Percentage of Rocks	Number of Rocks	Total Kinetic Energy [KJ]	Percentage of Rocks	Number of Rocks	Total Kinetic Energy [KJ]	Percentage of Rocks
1	Erzberg	3	1	126	33.3%	1	126 ~ 270	33.3%	1	270 ~ 357	33.3%
2	Glenwood Canyon, USA	4167	4056	970	97.3%	105	970 ~ 2521	2.52%	6	2521 ~ 6397	0.1%
3	Limestone quarry in England	4	4	42	100.0%						
4	Atrani, Campania, Southern Italy	0									
5	Italcementi works at Castellammare di Stabia	419	400	1383	95.5%	15	1383 ~ 3040	3.58%	4	3040 ~ 9118	1.0%
6	Colorado, USA	3577	3315	485	92.7%	245	485 ~ 1644	6.85%	17	1644 ~ 3386	0.5%
7	Mountain road, near Bolzano, Soth Tyrol, Italy	7445	7187	4161	96.5%	240	4161 ~ 10103	3.22%	18	10103 ~ 19612	0.2%
8	170m deep open pit, Australia	4513	4366	3005	96.7%	127	3005 ~ 8155	2.81%	20	8155 ~ 14163	0.4%

Table 29: Profile I - Present Situation - Total Kinetic Energy on Barrier

Profile II - Present Situation - Total Kinetic Energy on the Barrier											
No.	Location	Total Number of Rocks	Probable (Scenario A)			Between Probable and Improbable (Scenario B)			Improbable (Scenario C)		
			Number of Rocks	Total Kinetic Energy [KJ]	Percentage of Rocks	Number of Rocks	Total Kinetic Energy [KJ]	Percentage of Rocks	Number of Rocks	Total Kinetic Energy [KJ]	Percentage of Rocks
1	Erzberg	9	7	113	77.8%	2	113 ~ 382	22.2%			
2	Glenwood Canyon, USA	5037	4826	570	95.8%	200	570 ~ 1455	3.97%	11	1455 ~ 2087	0.2%
3	Limestone quarry in England	2	1	53	50.0%	1	53 ~ 417	50.00%	0	417 ~ 417	0.0%
4	Atrani, Campania, Southern Italy	0									
5	Italcementi works at Castellammare di Stabia	2546	2436	1432	95.7%	70	1432 ~ 3476	2.75%	40	3476 ~ 6748	1.6%
6	Colorado, USA	5686	5613	807	98.7%	71	807 ~ 2744	1.25%	2	2744 ~ 5326	0.0%
7	Mountain road, near Bolzano, Soth Tyrol, Italy	7918	7680	2968	97.0%	226	2968 ~ 6359	2.85%	12	6359 ~ 13990	0.2%
8	170m deep open pit, Australia	3952	3843	2113	97.2%	86	2113 ~ 4526	2.18%	23	4526 ~ 9957	0.6%

Table 30: Profile II - Present Situation - Total Kinetic Energy on Barrier

Profile III - Present Situation - Total Kinetic Energy on the Barrier

No.	Location	Total Number of Rocks	Probable (Scenario A)			Between Probable and Improbable (Scenario B)			Improbable (Scenario C)		
			Number of Rocks	Total Kinetic Energy [KJ]	Percentage of Rocks	Number of Rocks	Total Kinetic Energy [KJ]	Percentage of Rocks	Number of Rocks	Total Kinetic Energy [KJ]	Percentage of Rocks
1	Erzberg	0									
2	Glenwood Canyon, USA	6428	6337	948	98.6%	88	948 ~ 1981	1.37%	3	1981 ~ 2842	0.0%
3	Limestone quarry in England	16	11	95	68.8%	5	95 ~ 237	31.25%			
4	Atrani, Campania, Southern Italy	0									
5	Italcementi works at Castellammare di Stabia	2988	2955	2812	98.9%	29	2812 ~ 7185	0.97%	4	7185 ~ 10309	0.1%
6	Colorado, USA	6127	6061	997	98.9%	66	997 ~ 1934	1.08%			
7	Mountain road, near Bolzano, Soth Tyrol, Italy	6968	6821	2780	97.9%	128	2780 ~ 6484	1.84%	19	6484 ~ 10189	0.3%
8	170m deep open pit, Australia	4426	4357	2252	98.4%	46	2252 ~ 4824	1.04%	23	4824 ~ 10611	0.5%

Table 31: Profile III - Present Situation - Total Kinetic Energy on Barrier

Profile IV - Present Situation - Total Kinetic Energy on the Barrier

No.	Location	Total Number of Rocks	Probable (Scenario A)			Between Probable and Improbable (Scenario B)			Improbable (Scenario C)		
			Number of Rocks	Total Kinetic Energy [KJ]	Percentage of Rocks	Number of Rocks	Total Kinetic Energy [KJ]	Percentage of Rocks	Number of Rocks	Total Kinetic Energy [KJ]	Percentage of Rocks
1	Erzberg	7	7	109	100.0%						
2	Glenwood Canyon, USA	4642	4585	1000	98.8%	57	1000 ~ 1941	1.23%			
3	Limestone quarry in England	40	37	155	92.5%	3	155 ~ 465	7.50%			
4	Atrani, Campania, Southern Italy	0									
5	Italcementi works at Castellammare di Stabia	5477	5413	2444	98.8%	57	2444 ~ 5935	1.04%	7	5935 ~ 11519	0.1%
6	Colorado, USA	4105	4050	920	98.7%	55	920 ~ 2758	1.34%			
7	Mountain road, near Bolzano, Soth Tyrol, Italy	7179	6954	2263	96.9%	209	2263 ~ 5278	2.91%	16	5278 ~ 8293	0.2%
8	170m deep open pit, Australia	3993	3893	1471	97.5%	87	1471 ~ 4412	2.18%	13	4412 ~ 6933	0.3%

Table 32: Profile IV - Present Situation - Total Kinetic Energy on Barrier

Profile I - Filled Berms - Total Kinetic Energy on the Barrier											
No.	Location	Total Number of Rocks	Probable (Scenario A)			Between Probable and Improbable (Scenario B)			Improbable (Scenario C)		
			Number of Rocks	Total Kinetic Energy [KJ]	Percentage of Rocks	Number of Rocks	Total Kinetic Energy [KJ]	Percentage of Rocks	Number of Rocks	Total Kinetic Energy [KJ]	Percentage of Rocks
1	Erzberg	0									
2	Glenwood Canyon, USA	9168	8868	1997	96.7%	300	1997 ~ 5069	3.27%			
3	Limestone quarry in England	5	5	168	100.0%						
4	Atrani, Campania, Southern Italy	0									
5	Italcementi works at Castellammare di Stabia	3991	3850	1457	96.5%	131	1457 ~ 3074	3.28%	10	3074 ~ 5339	0.3%
6	Colorado, USA	8661	8489	1962	98.0%	156	1962 ~ 2967	1.80%	16	2967 ~ 4979	0.2%
7	Mountain road, near Bolzano, Soth Tyrol, Italy	11772	11392	3401	96.8%	370	3401 ~ 6017	3.14%	10	6017 ~ 8633	0.1%
8	170m deep open pit, Australia	10015	9767	1597	97.5%	248	1597 ~ 3514	2.48%			

Table 33: Profile I - Filled Berms - Total Kinetic Energy on Barrier

Profile II - Filled Berms - Total Kinetic Energy on the Barrier											
No.	Location	Total Number of Rocks	Probable (Scenario A)			Between Probable and Improbable (Scenario B)			Improbable (Scenario C)		
			Number of Rocks	Total Kinetic Energy [KJ]	Percentage of Rocks	Number of Rocks	Total Kinetic Energy [KJ]	Percentage of Rocks	Number of Rocks	Total Kinetic Energy [KJ]	Percentage of Rocks
1	Erzberg	1803	1653	907	91.7%	146	907 ~ 2061	8.1%	4	2061 ~ 2721	0.2%
2	Glenwood Canyon, USA	9867	9730	3934	98.6%	137	3934 ~ 6181	1.39%			
3	Limestone quarry in England	154	151	983	98.1%	3	983 ~ 3600	1.95%			
4	Atrani, Campania, Southern Italy	0									
5	Italcementi works at Castellammare di Stabia	5588	5340	2460	95.6%	211	2460 ~ 3974	3.78%	37	3974 ~ 6245	0.7%
6	Colorado, USA	9858	9515	3160	96.5%	343	3160 ~ 6133	3.48%			
7	Mountain road, near Bolzano, Soth Tyrol, Italy	9997	9602	3986	96.0%	390	3986 ~ 6331	3.90%	5	6331 ~ 7737	0.1%
8	170m deep open pit, Australia	9948	9719	2537	97.7%	229	2537 ~ 4405	2.30%			

Table 34: Profile II - Filled Berms - Total Kinetic Energy on Barrier

Profile III - Filled Berms - Total Kinetic Energy on the Barrier											
No.	Location	Total Number of Rocks	Probable (Scenario A)			Between Probable and Improbable (Scenario B)			Improbable (Scenario C)		
			Number of Rocks	Total Kinetic Energy [KJ]	Percentage of Rocks	Number of Rocks	Total Kinetic Energy [KJ]	Percentage of Rocks	Number of Rocks	Total Kinetic Energy [KJ]	Percentage of Rocks
1	Erzberg	1539	1442	1054	93.7%	97	1054 ~ 2675	6.3%			
2	Glenwood Canyon, USA	9769	9534	3525	97.6%	235	3525 ~ 6122	2.41%			
3	Limestone quarry in England	166	153	515	92.2%	12	515 ~ 1954	7.23%	1	1954 ~ 3393	0.6%
4	Atrani, Campania, Southern Italy	0									
5	Italcementi works at Castellammare di Stabia	5725	5528	2589	96.6%	190	2589 ~ 4943	3.32%	7	4943 ~ 7766	0.1%
6	Colorado, USA	9730	9664	4004	99.3%	66	4004 ~ 6292	0.68%			
7	Mountain road, near Bolzano, Soth Tyrol, Italy	9993	9698	4221	97.0%	295	4221 ~ 8193	2.95%			
8	170m deep open pit, Australia	9954	9719	2568	97.6%	235	2568 ~ 4983	2.36%			

Table 35: Profile III - Filled Berms - Total Kinetic Energy on Barrier

Profile IV - Filled Berms - Total Kinetic Energy on the Barrier											
No.	Location	Total Number of Rocks	Probable (Scenario A)			Between Probable and Improbable (Scenario B)			Improbable (Scenario C)		
			Number of Rocks	Total Kinetic Energy [KJ]	Percentage of Rocks	Number of Rocks	Total Kinetic Energy [KJ]	Percentage of Rocks	Number of Rocks	Total Kinetic Energy [KJ]	Percentage of Rocks
1	Erzberg	38	33	144	86.8%	5	144 ~ 361	13.2%			
2	Glenwood Canyon, USA	8556	8507	1478	99.4%	49	1478 ~ 2567	0.57%			
3	Limestone quarry in England	115	105	171	91.3%	10	171 ~ 804	8.70%			
4	Atrani, Campania, Southern Italy	0									
5	Italcementi works at Castellammare di Stabia	5414	5391	2145	99.6%	16	2145 ~ 4052	0.30%	7	4052 ~ 7865	0.1%
6	Colorado, USA	10421	10405	2148	99.8%	16	2148 ~ 6444	0.15%			
7	Mountain road, near Bolzano, Soth Tyrol, Italy	12371	11907	3042	96.2%	378	3042 ~ 5807	3.06%	86	5807 ~ 9125	0.7%
8	170m deep open pit, Australia	11432	11381	1534	99.6%	48	1534 ~ 3725	0.42%	3	3725 ~ 7230	0.0%

Table 36: Profile IV - Filled Berms - Total Kinetic Energy on Barrier

Annex III: Bounce Height Graph

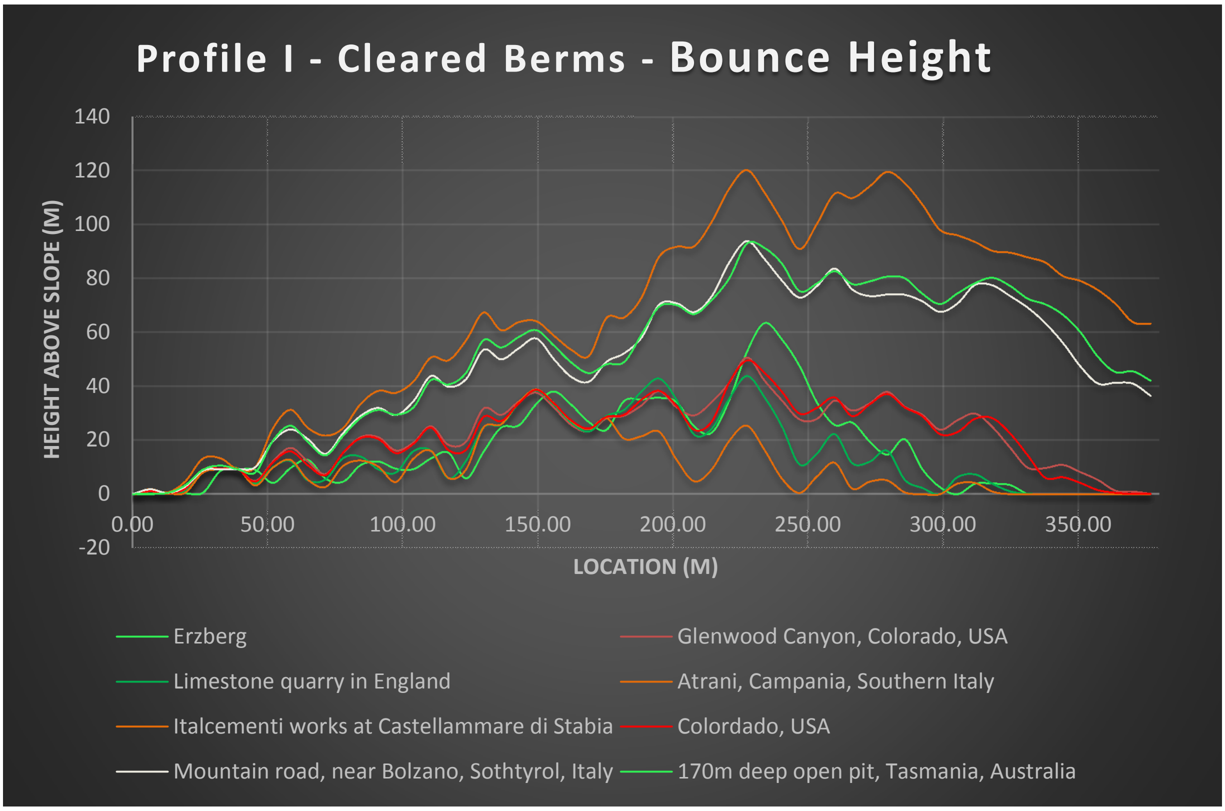

Figure 5: **Profile I - Cleared Berms - Bounce Height**

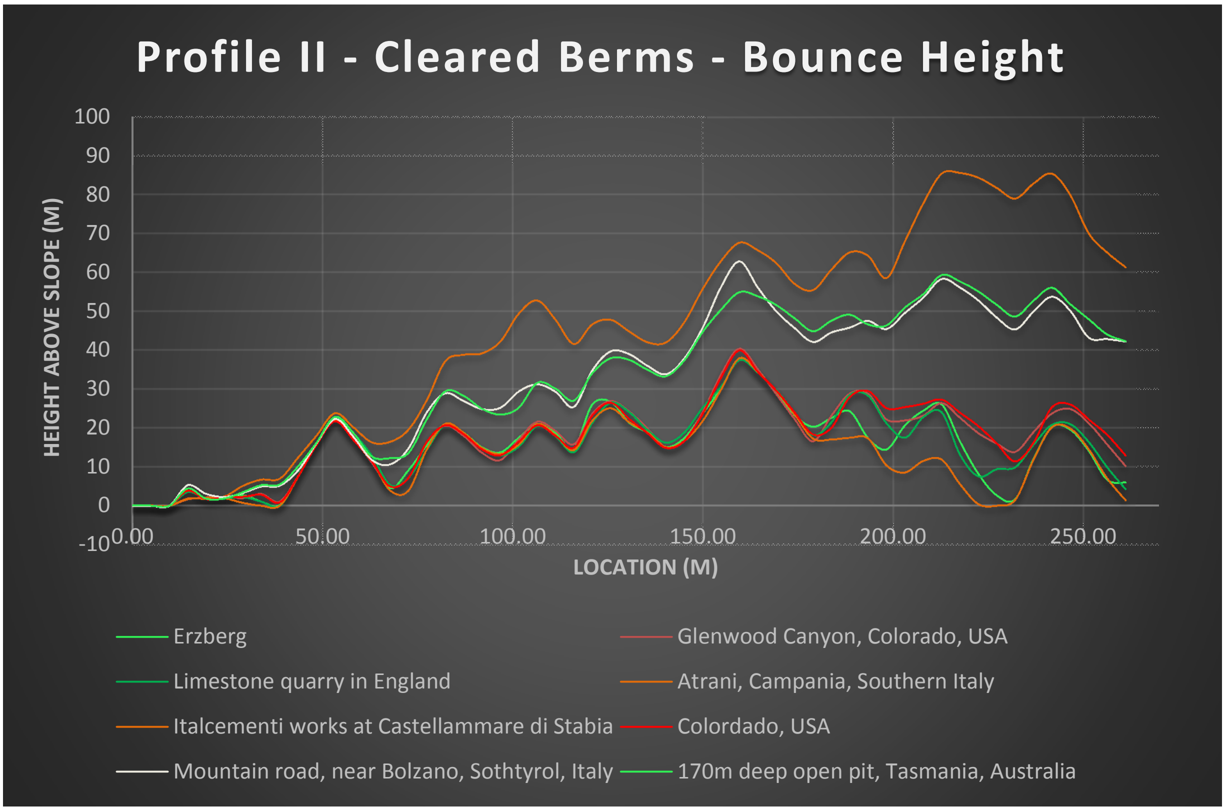

Figure 6: **Profile II - Cleared Berms - Bounce Height**

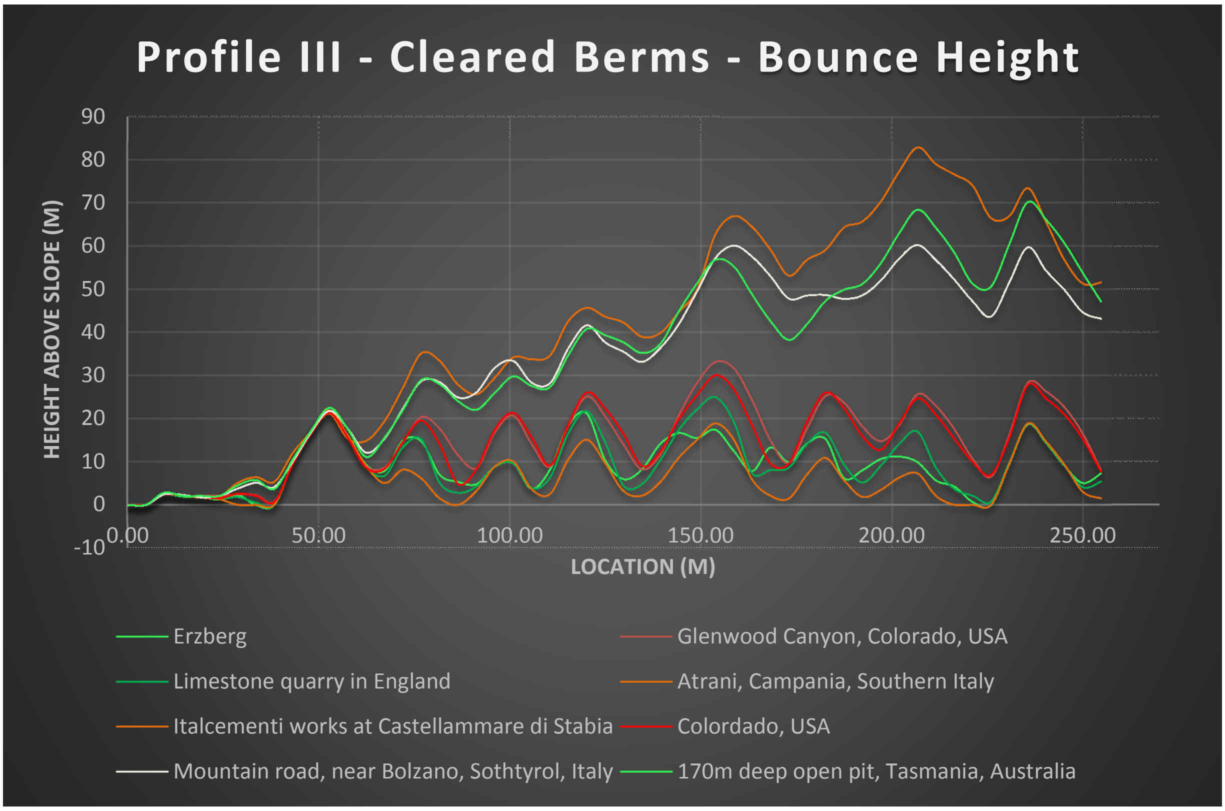

Figure 7: Profile III - Cleared Berms - Bounce Height

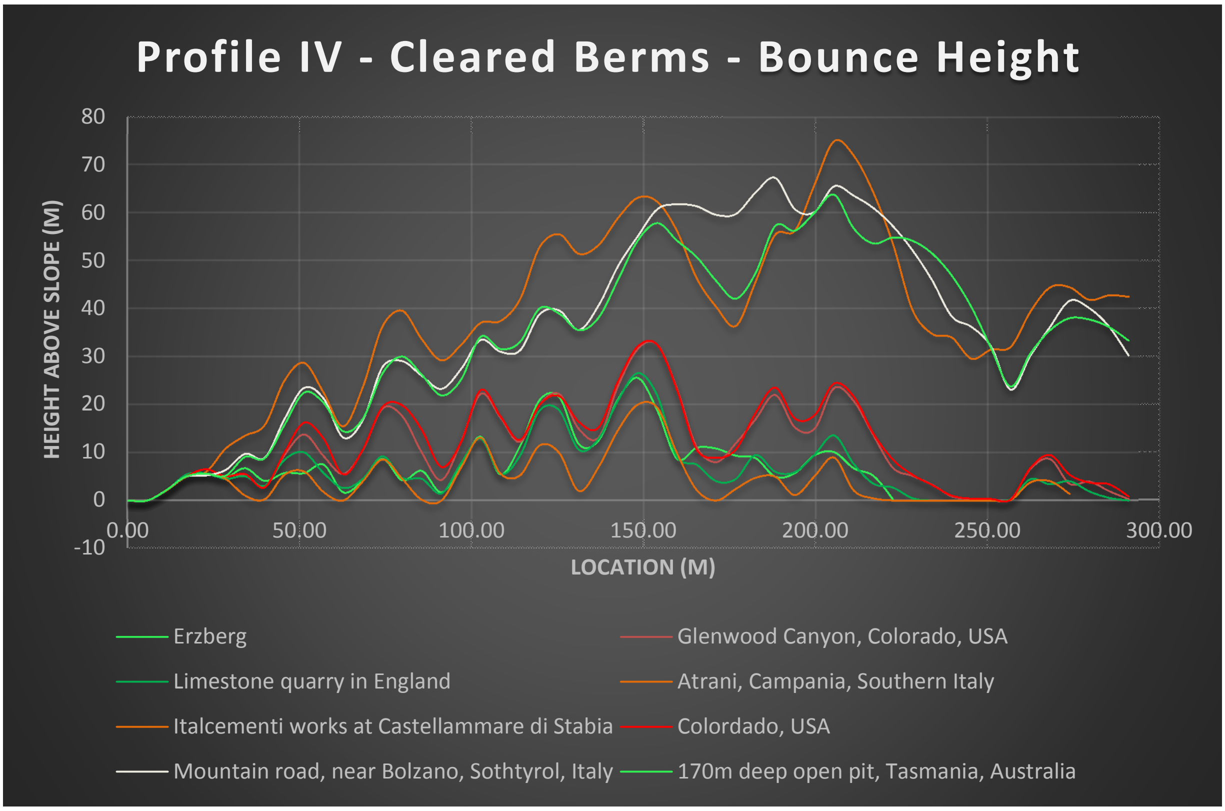

Figure 8: Profile IV - Cleared Berms - Bounce Height

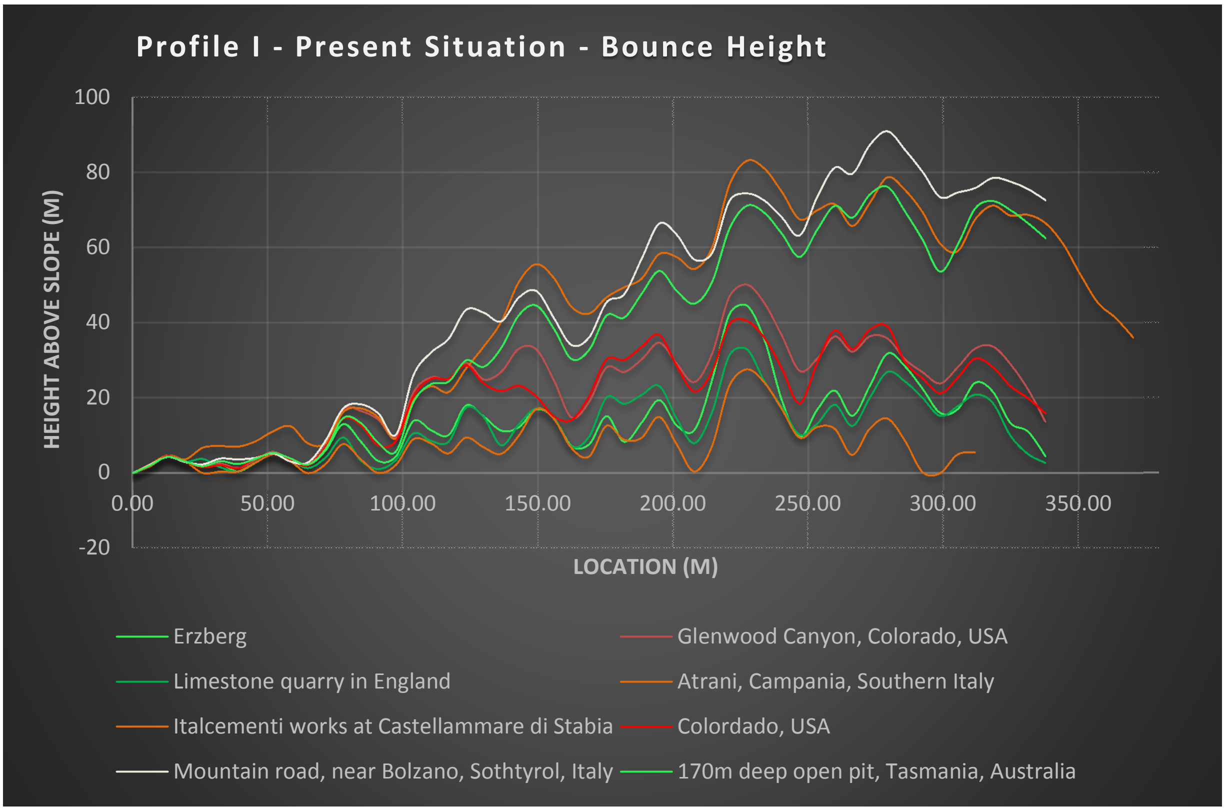

Figure 9: **Profile I - Present Situation - Bounce Height**

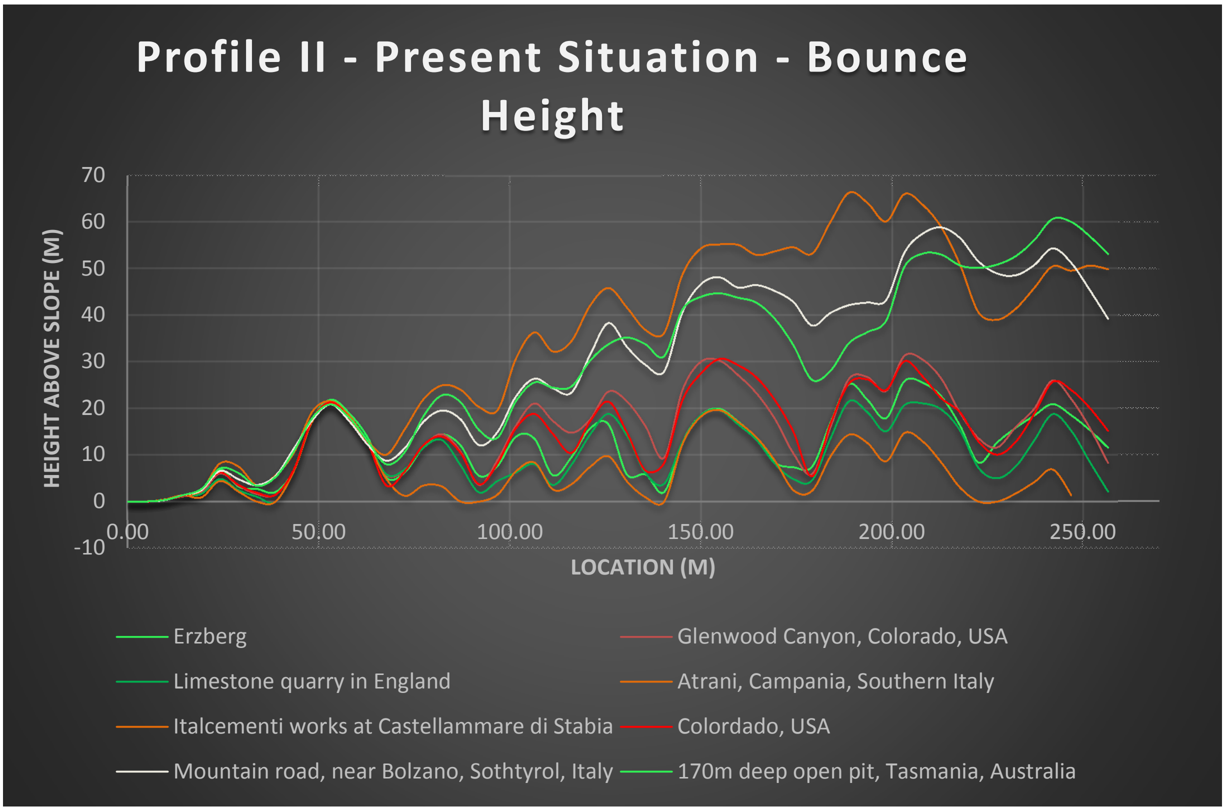

Figure 10: **Profile II - Present Situation - Bounce Height**

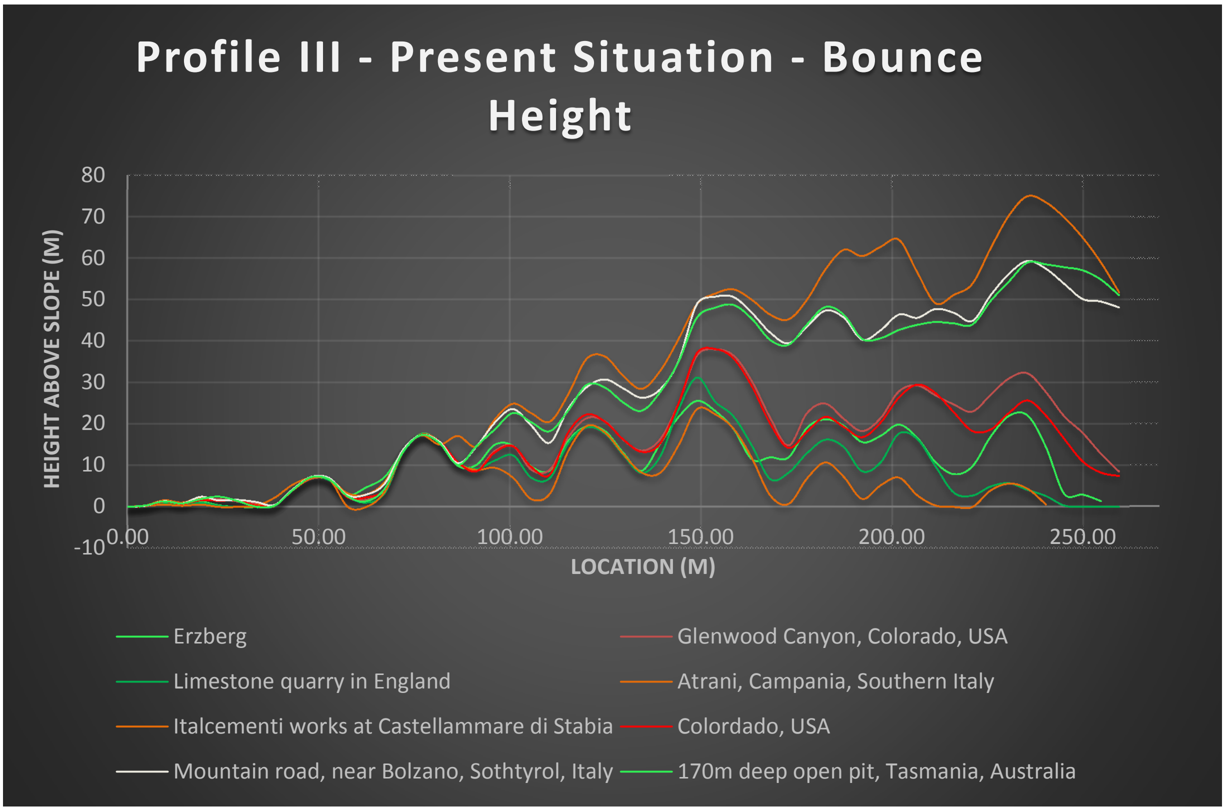

Figure 11: **Profile III - Present Situation - Bounce Height**

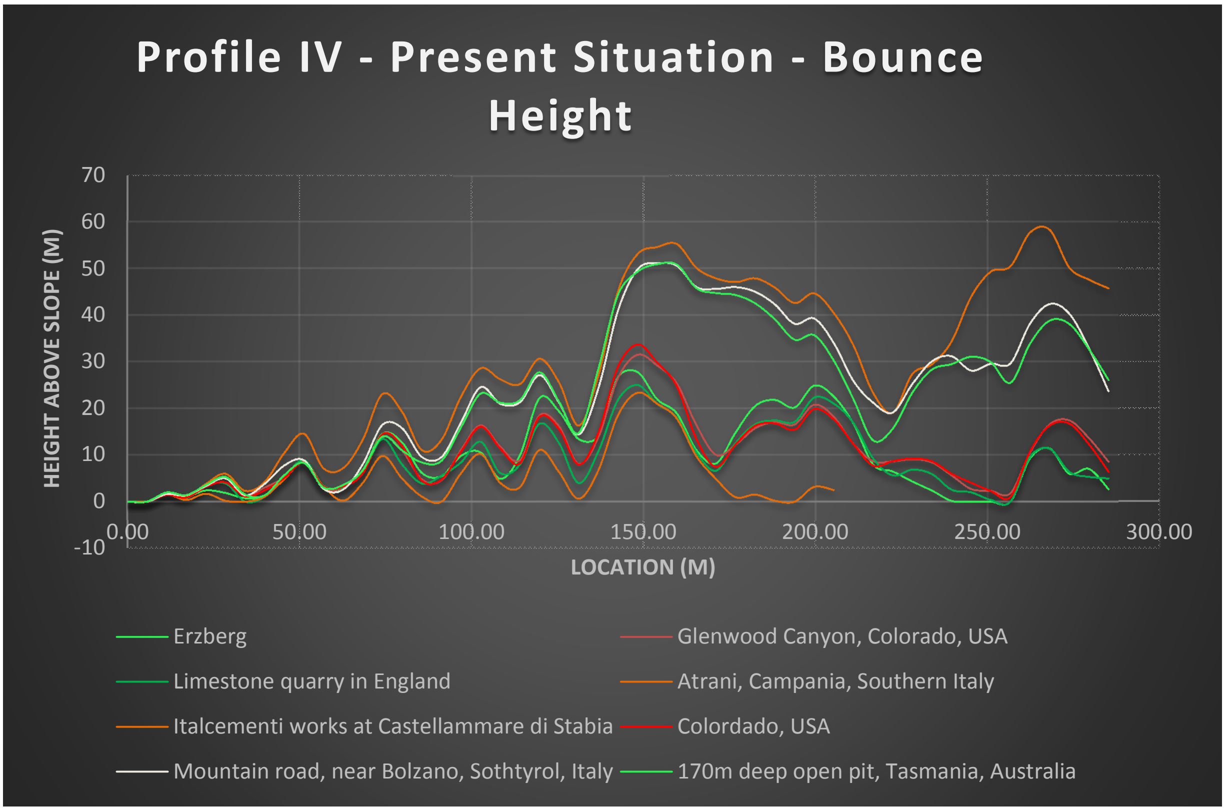

Figure 12: **Profile IV - Present Situation - Bounce Height**

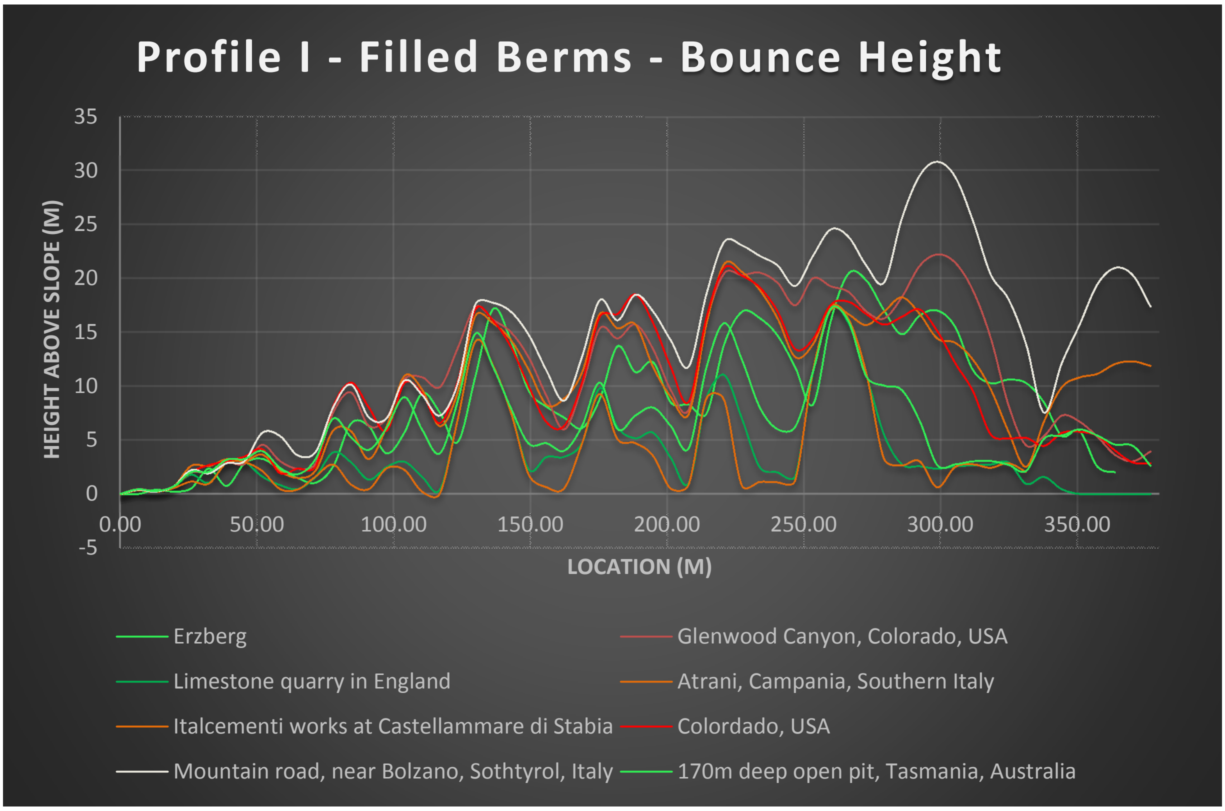

Figure 13: **Profile I - Filled Berms - Bounce Height**

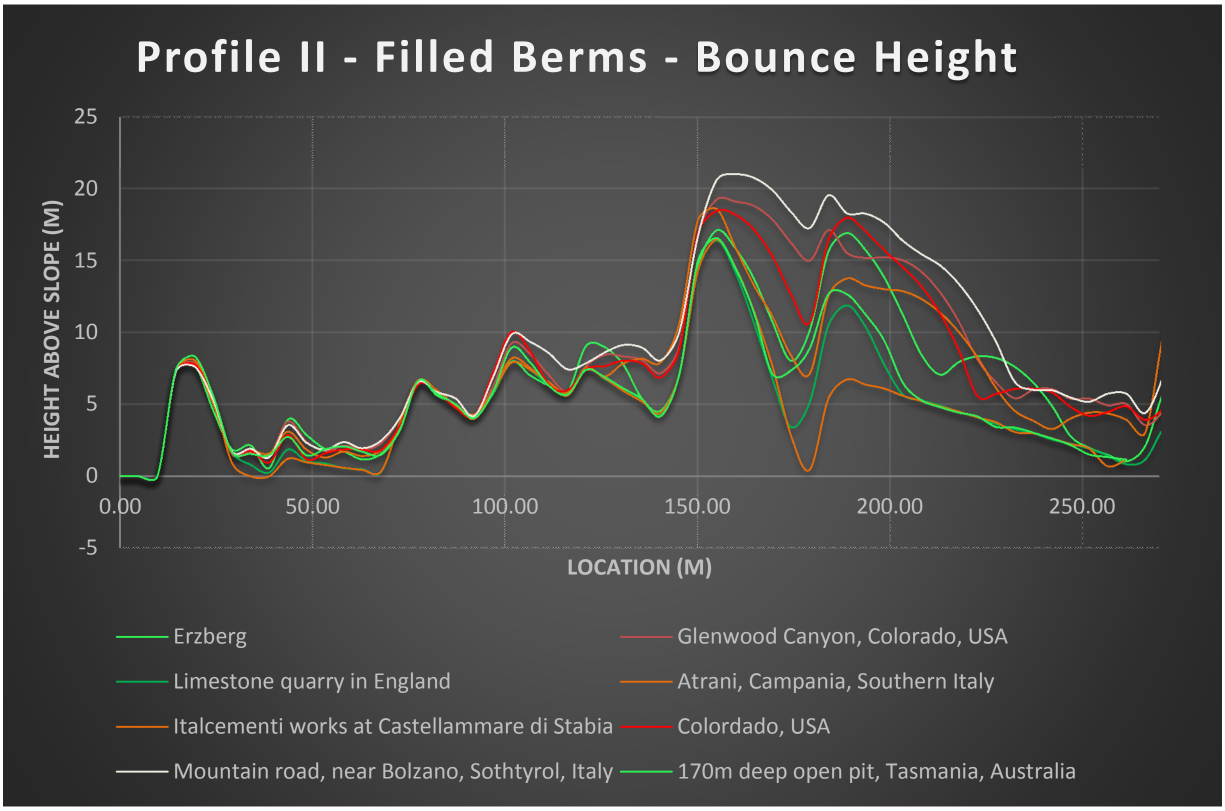

Figure 14: **Profile II - Filled Berms - Bounce Height**

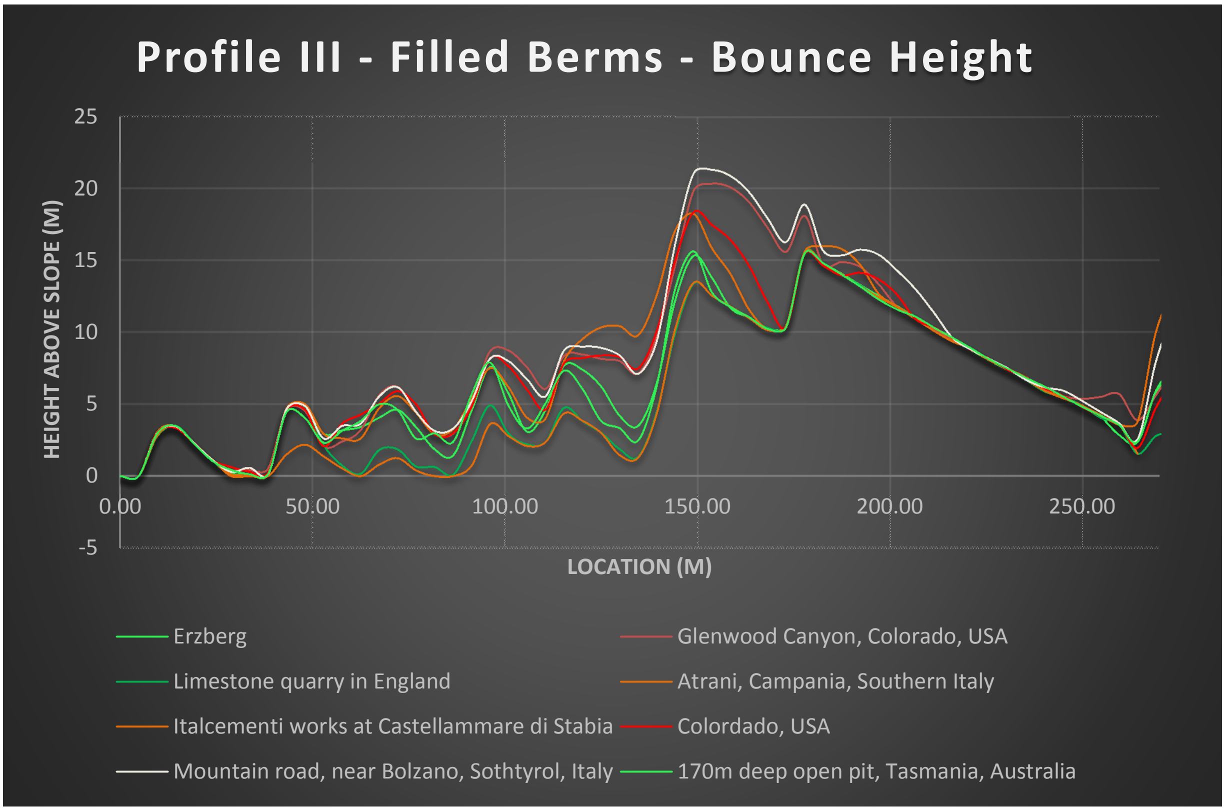

Figure 15: **Profile III - Filled Berms - Bounce Height**

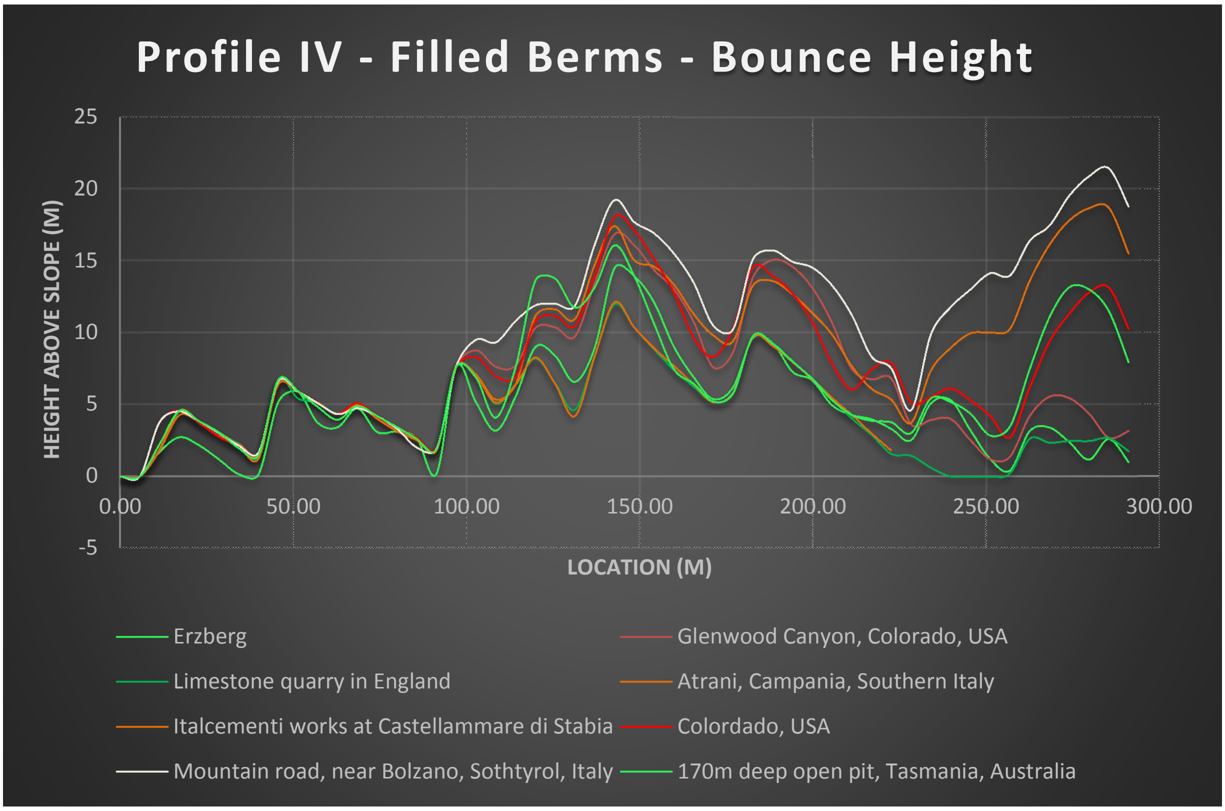

Figure 16: **Profile IV - Filled Berms - Bounce Height**

Annex IV: Total Kinetic Energy Graph

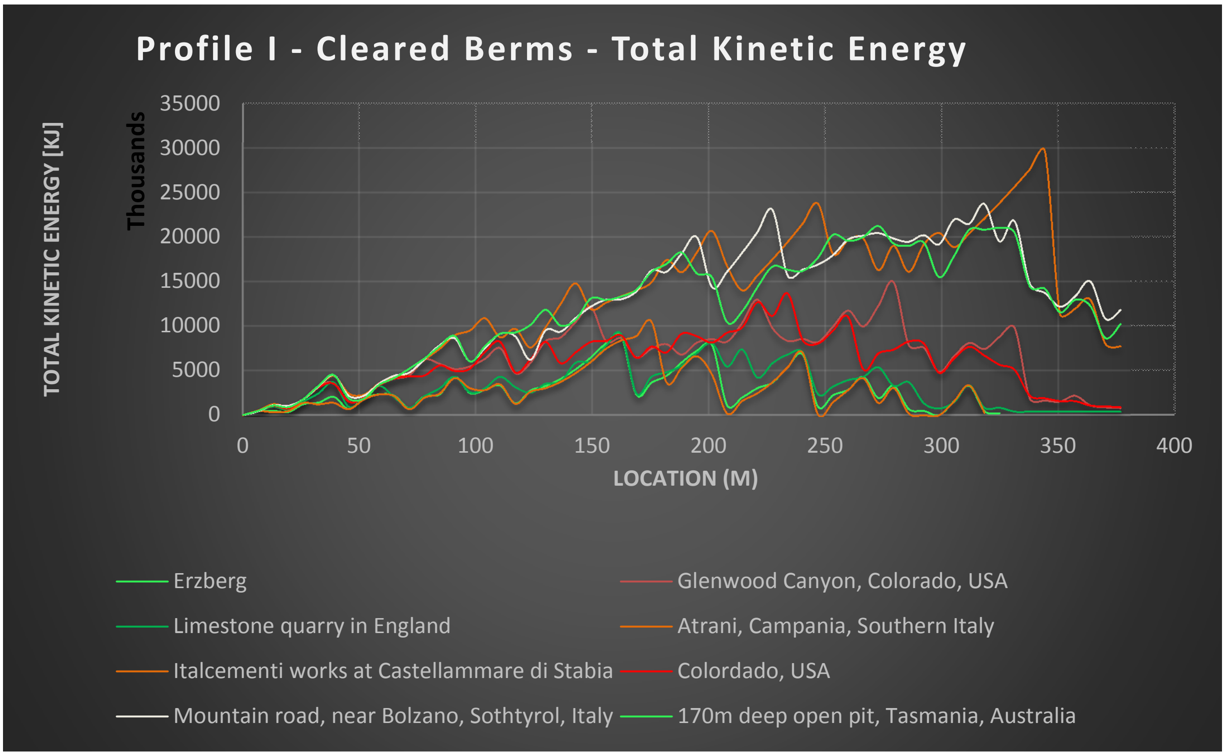

Figure 17: Profile I - Cleared Berms - Total Kinetic Energy

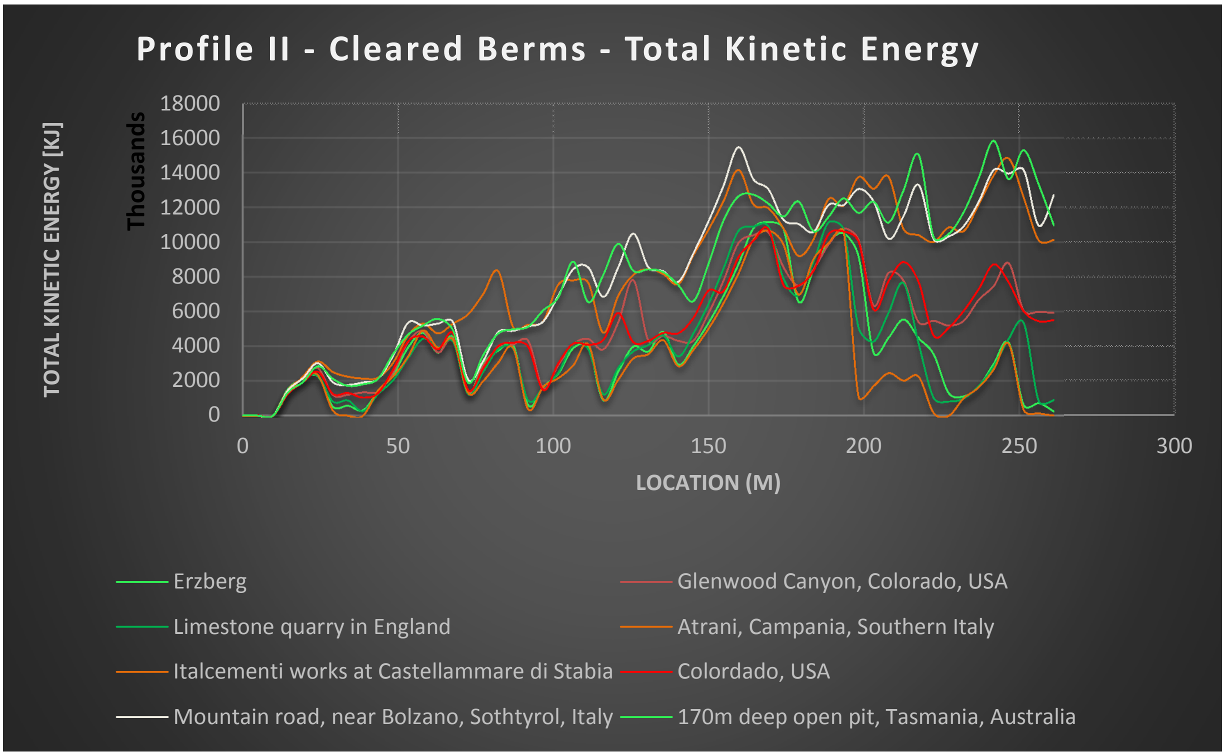

Figure 18: Profile II - Cleared Berms - Total Kinetic Energy

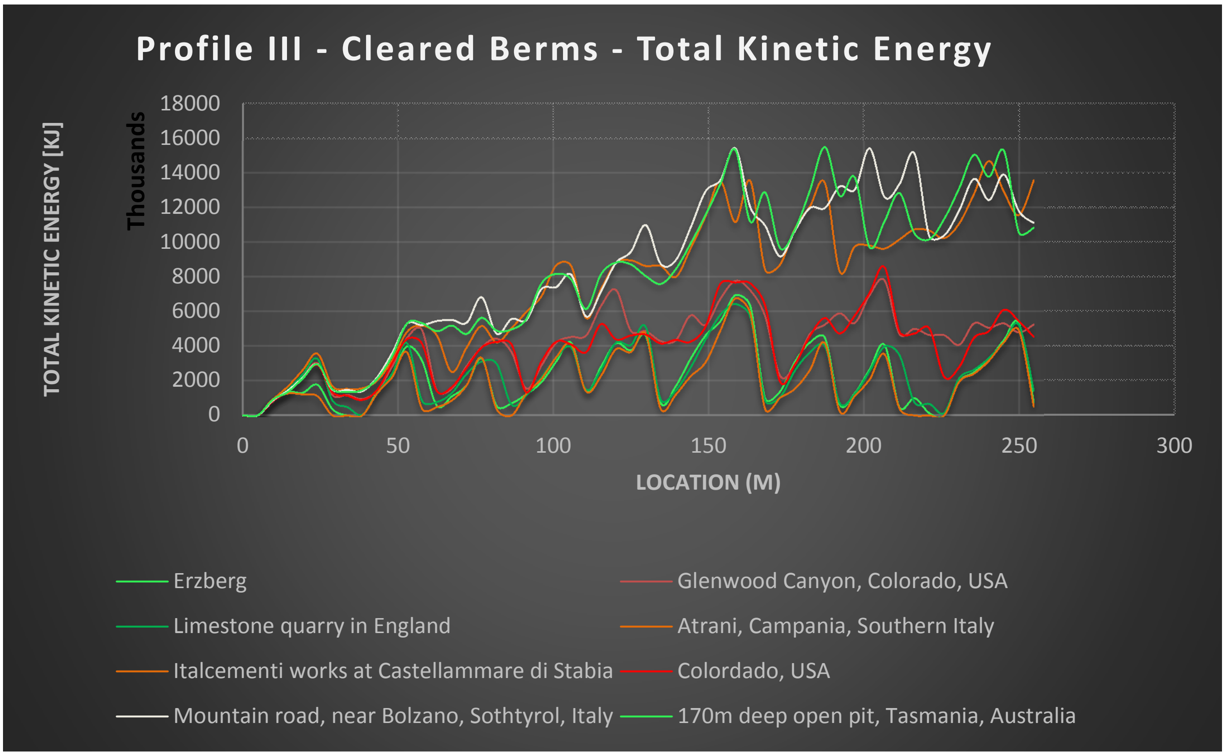

Figure 19: **Profile III - Cleared Berms - Total Kinetic Energy**

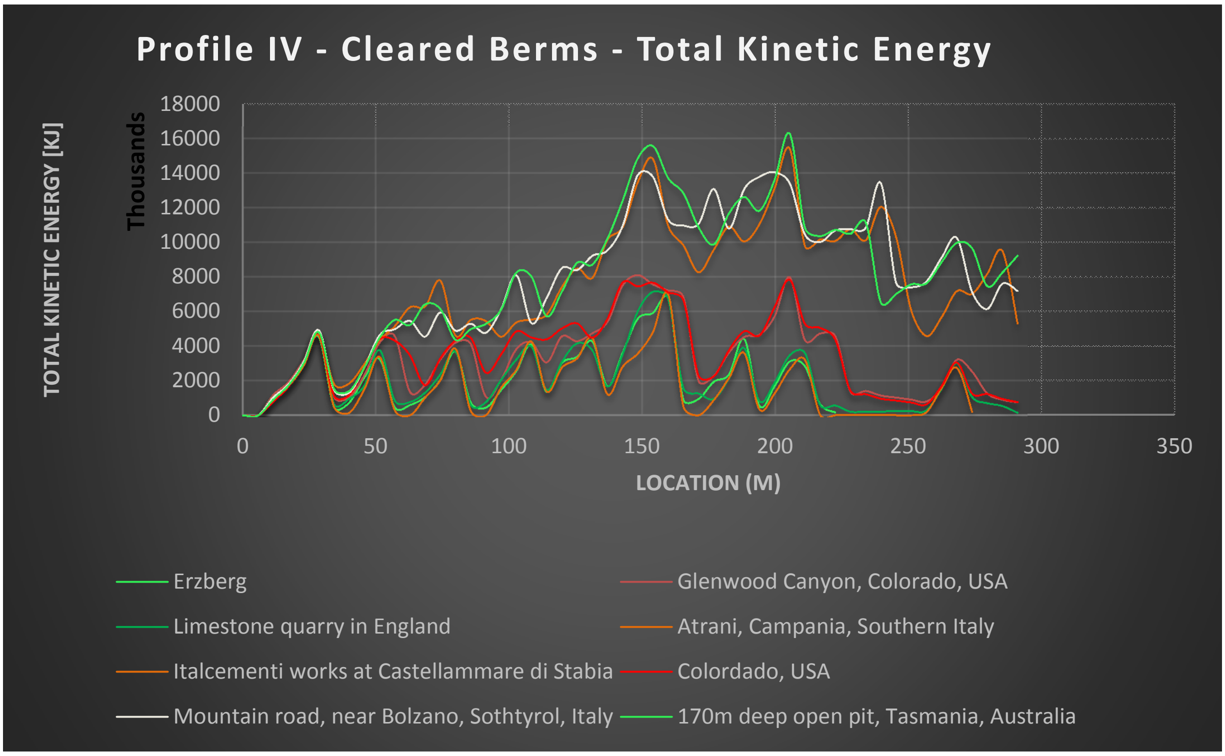

Figure 20: **Profile IV - Cleared Berms - Total Kinetic Energy**

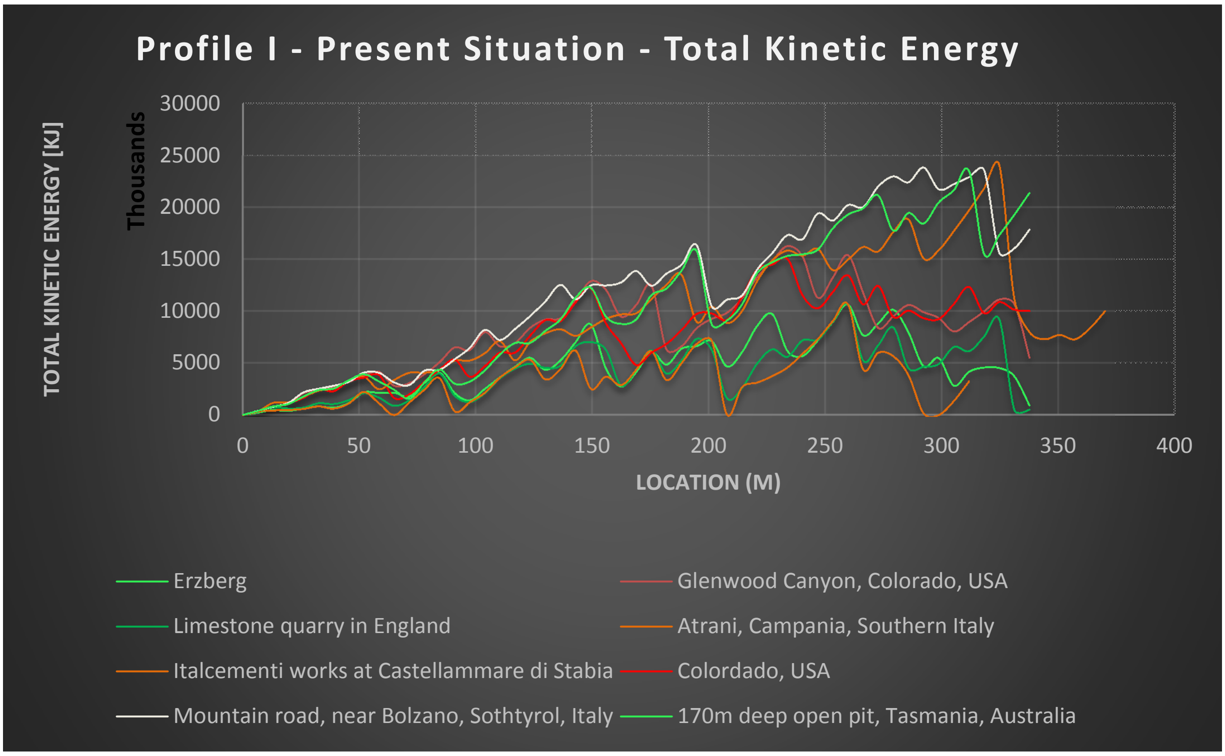

Figure 21: Profile I - Present Situation - Total Kinetic Energy

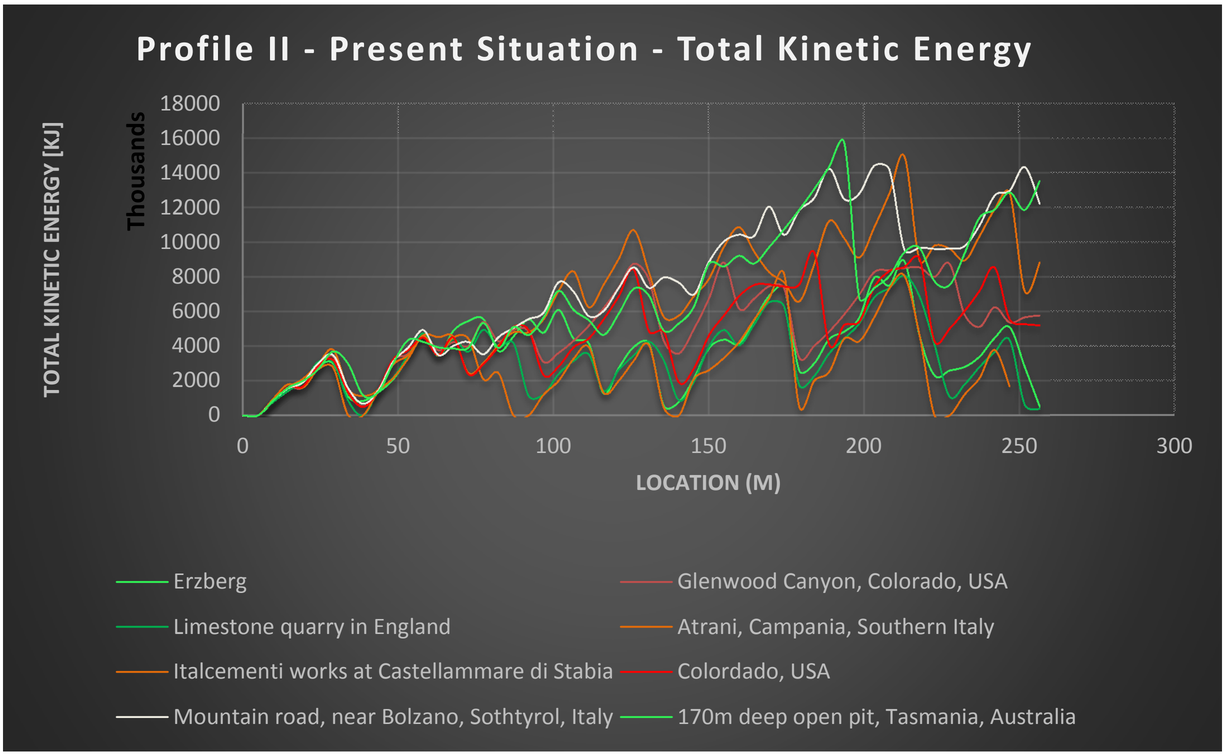

Figure 22: Profile II - Present Situation - Total Kinetic Energy

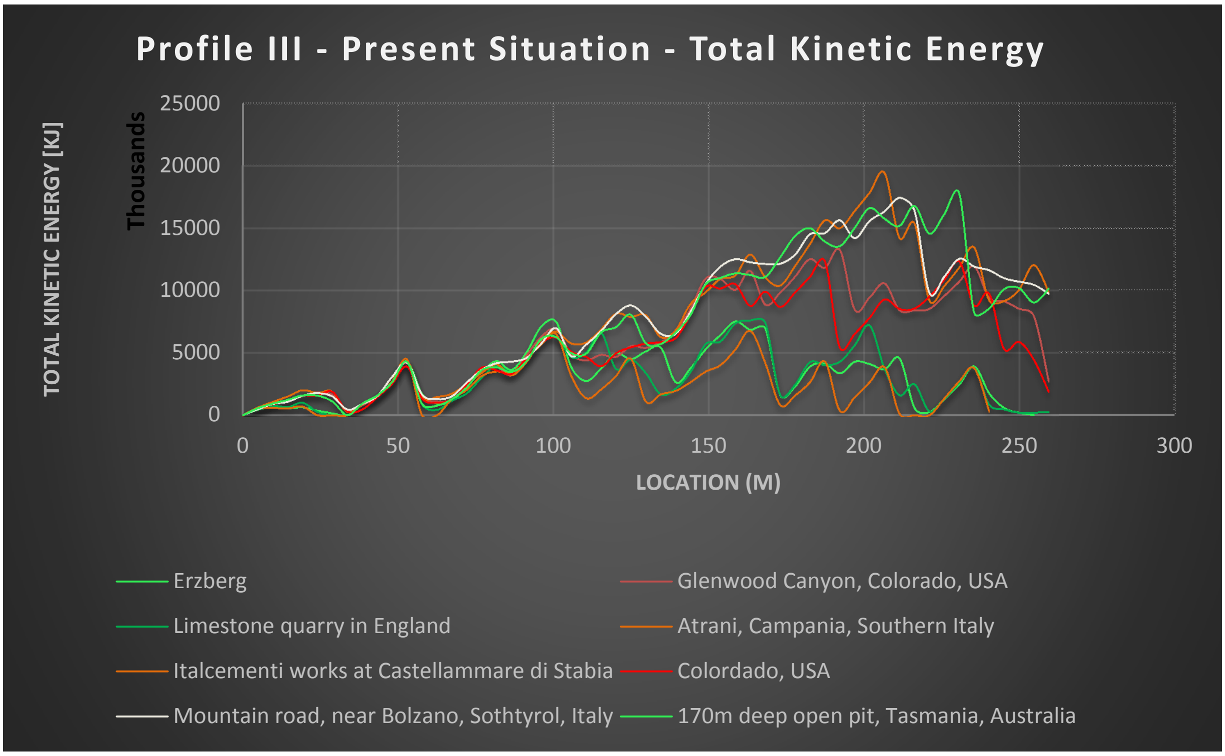

Figure 23: Profile III - Present Situation - Total Kinetic Energy

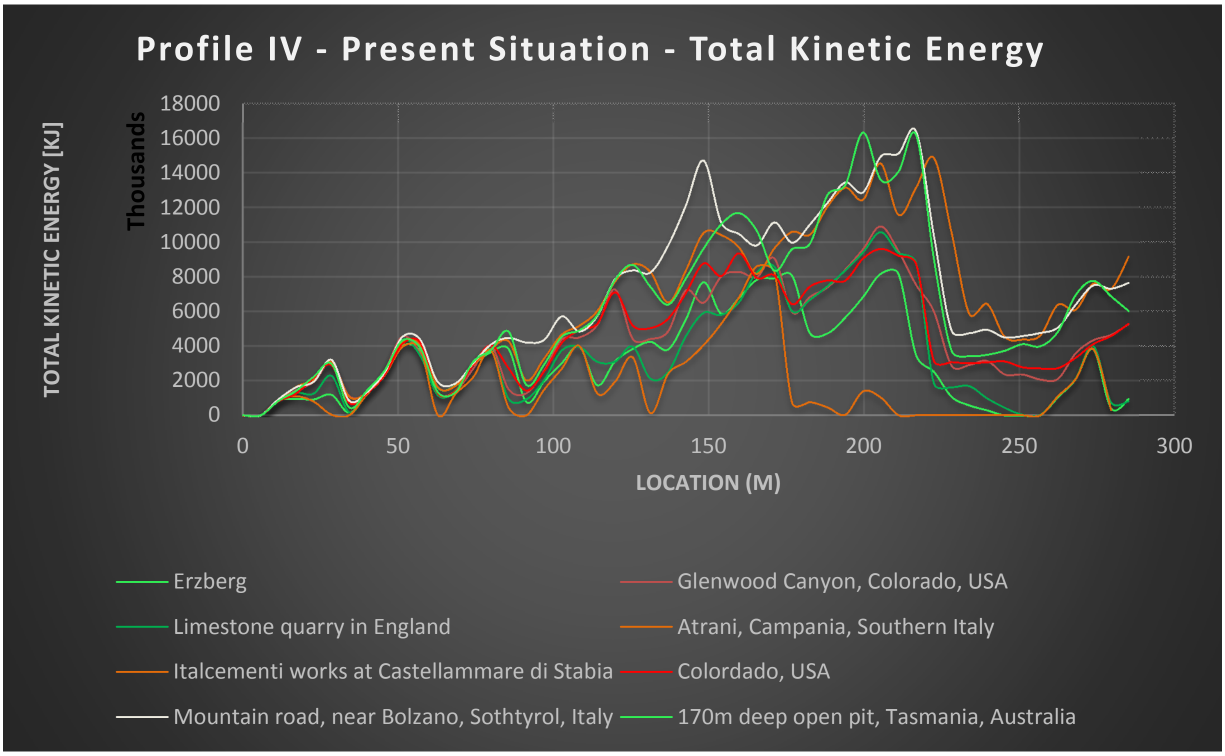

Figure 24: Profile IV - Present Situation - Total Kinetic Energy

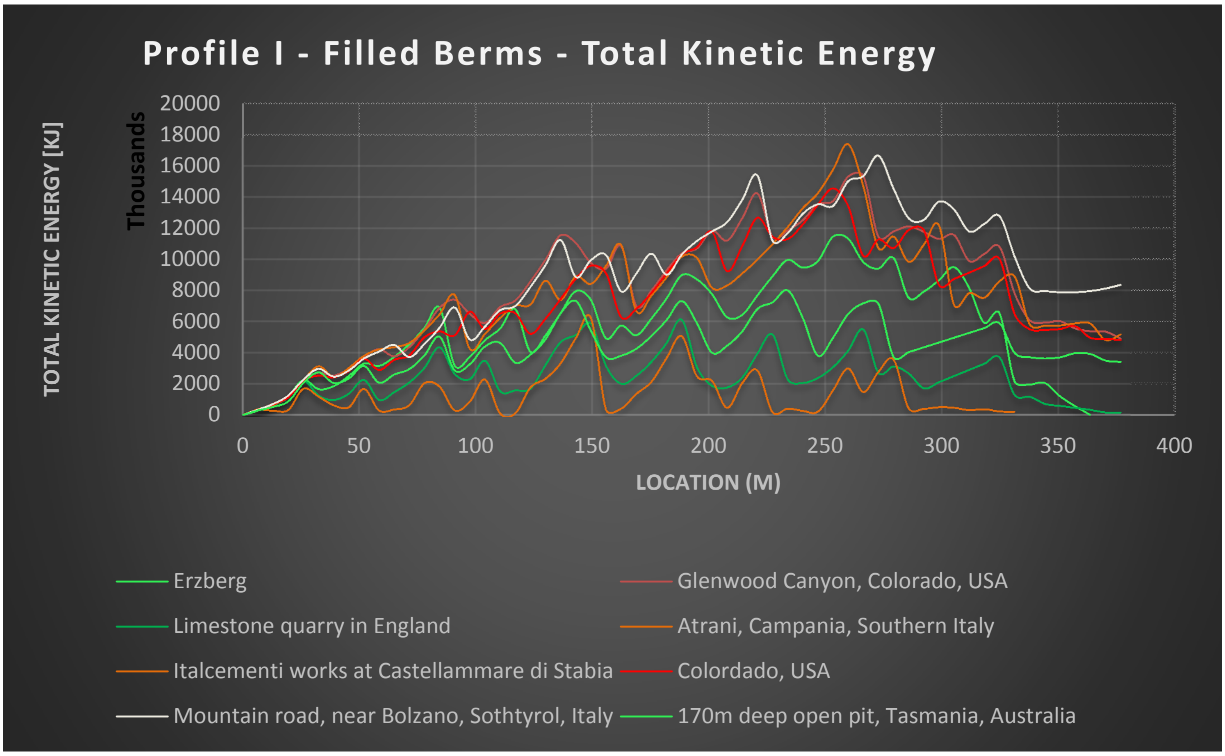

Figure 25: Profile I - Filled Berms - Total Kinetic Energy

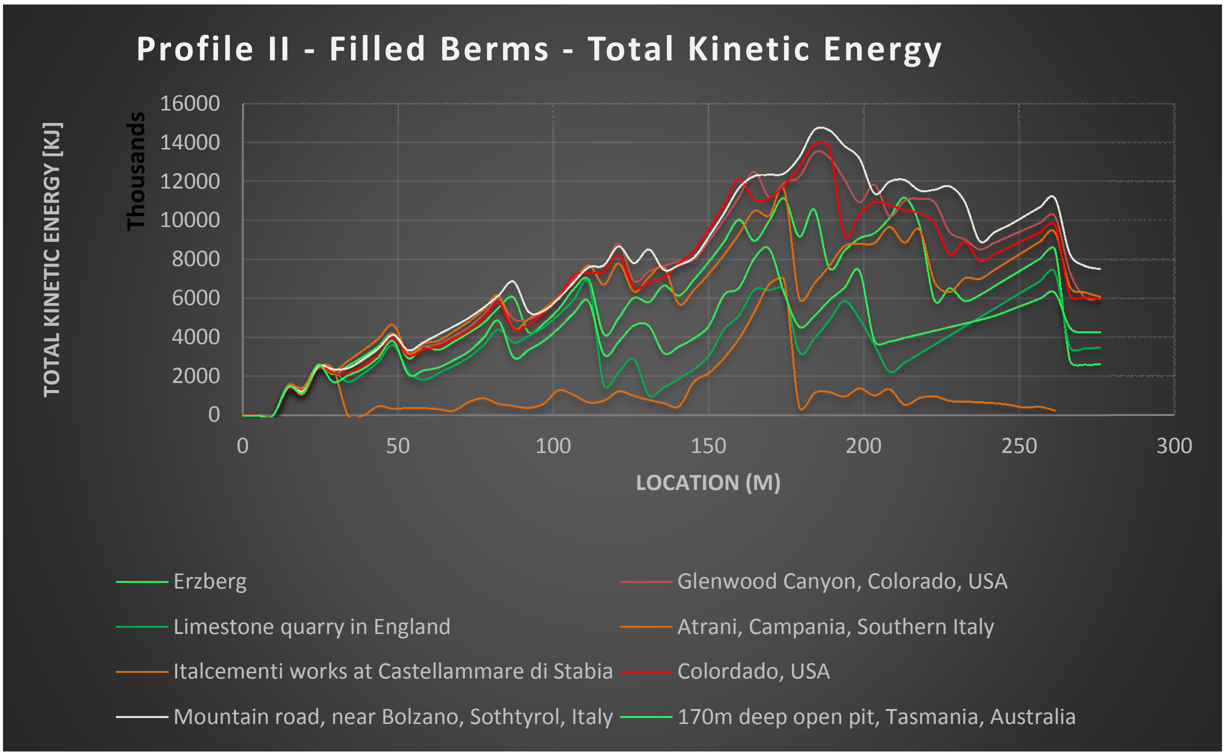

Figure 26: Profile II - Filled Berms - Total Kinetic Energy

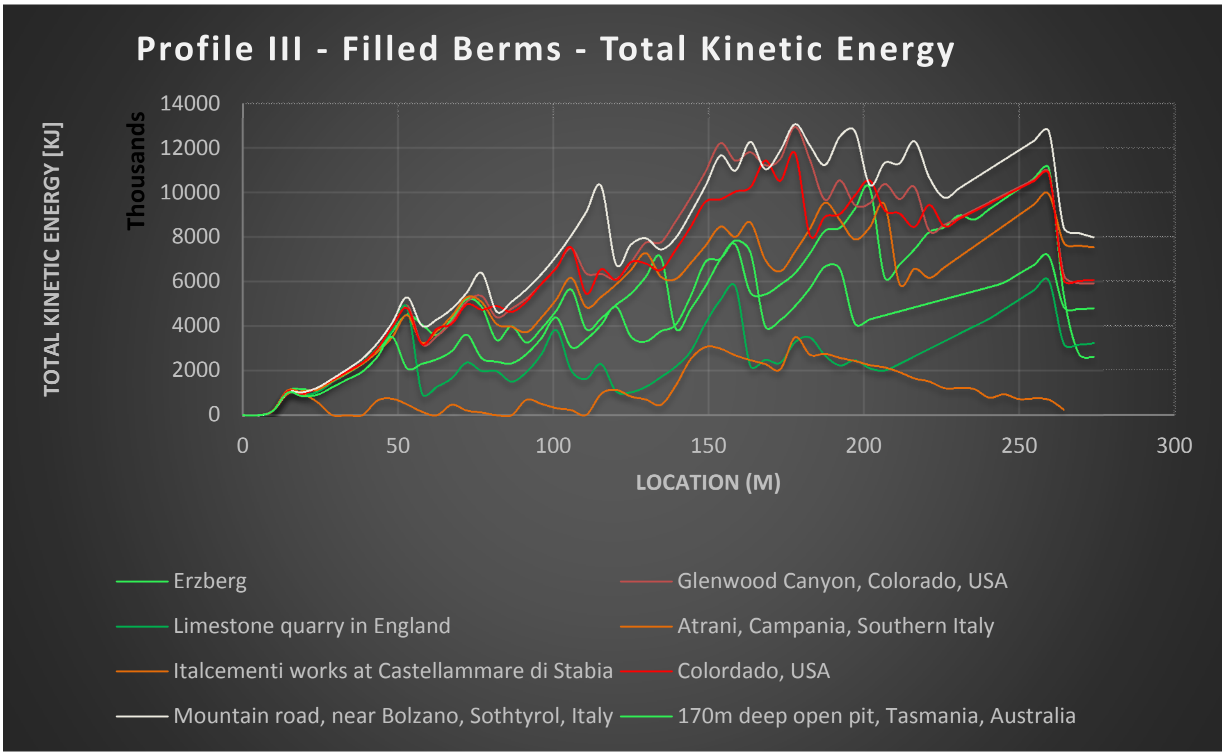

Figure 27: Profile III - Filled Berms - Total Kinetic Energy

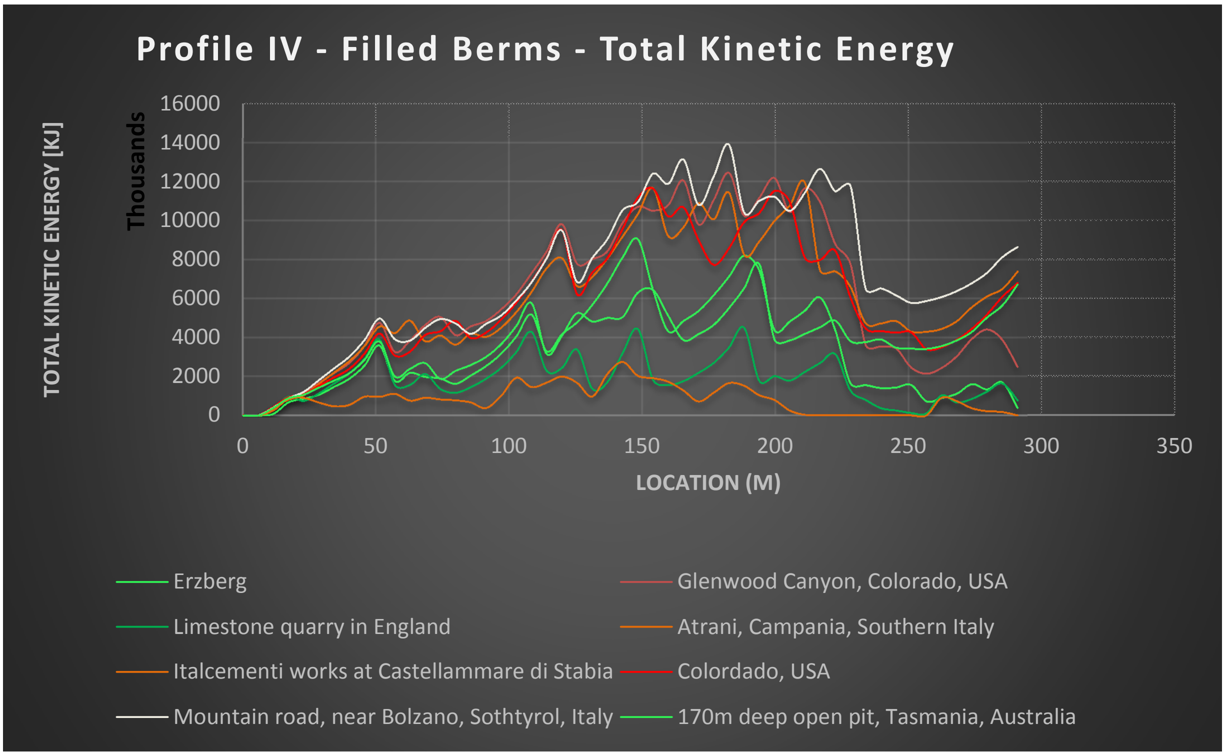

Figure 28: Profile IV - Filled Berms - Total Kinetic Energy

Annex V: X (Horizontal) Impact Locations

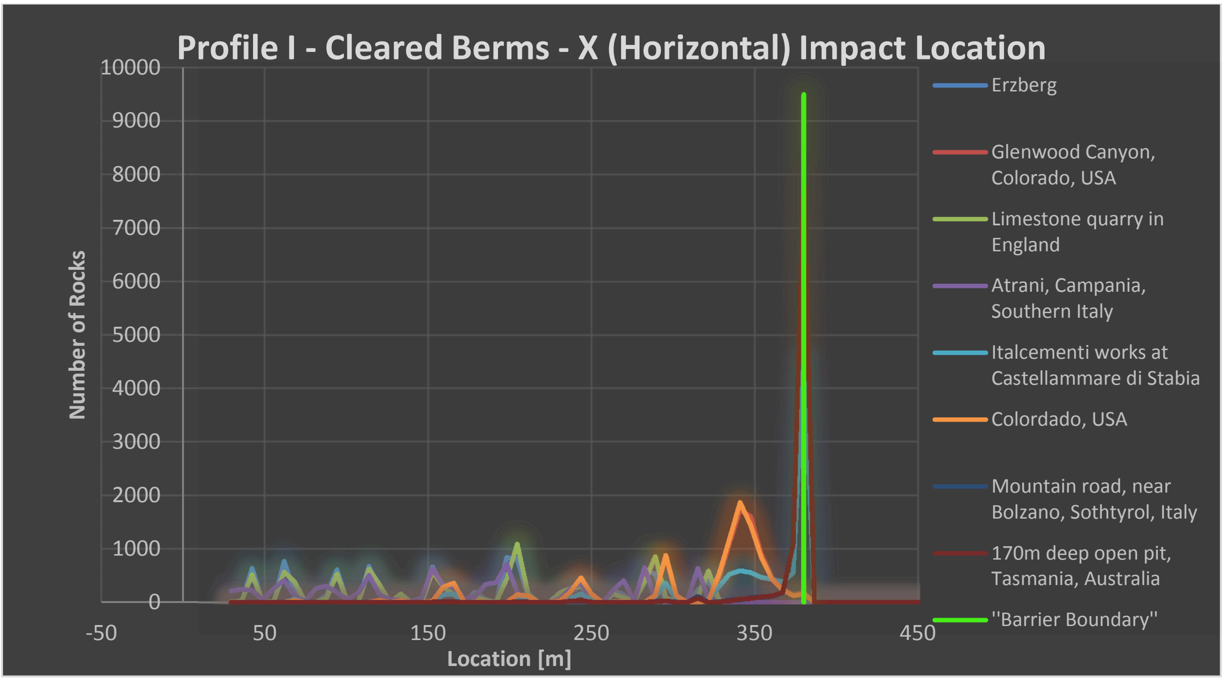

Figure 29: Profile I - Cleared Berms - X (Horizontal) Impact Location

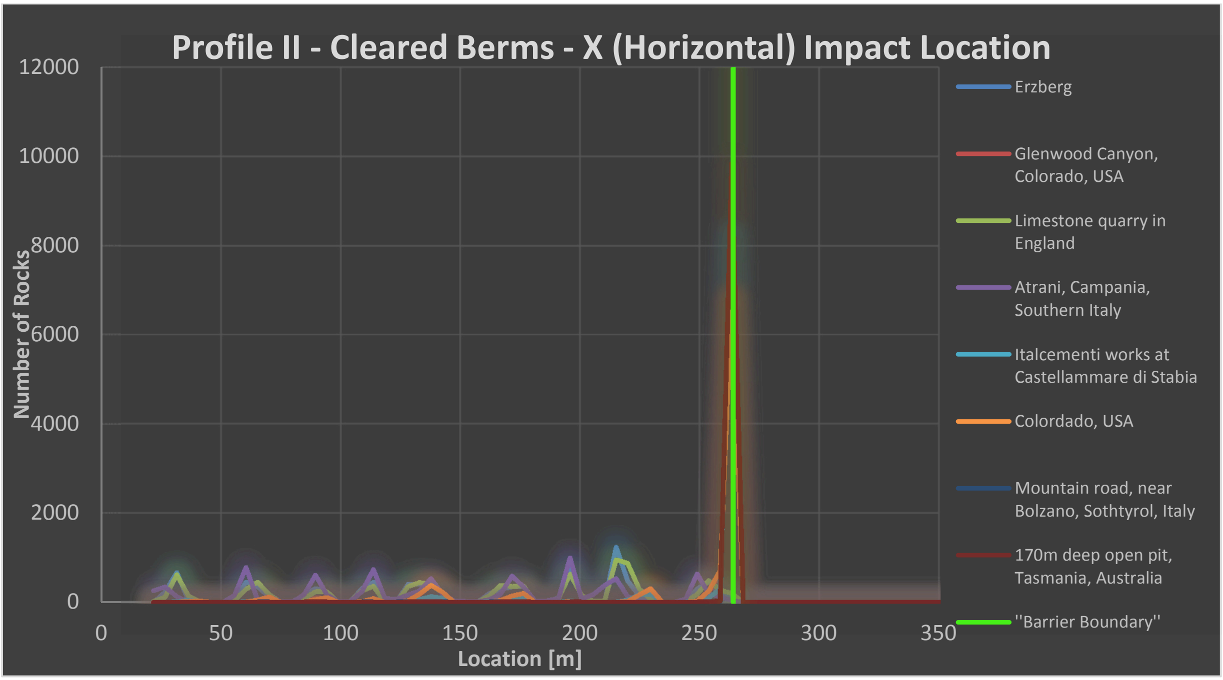

Figure 30: Profile II - Cleared Berms - X (Horizontal) Impact Location

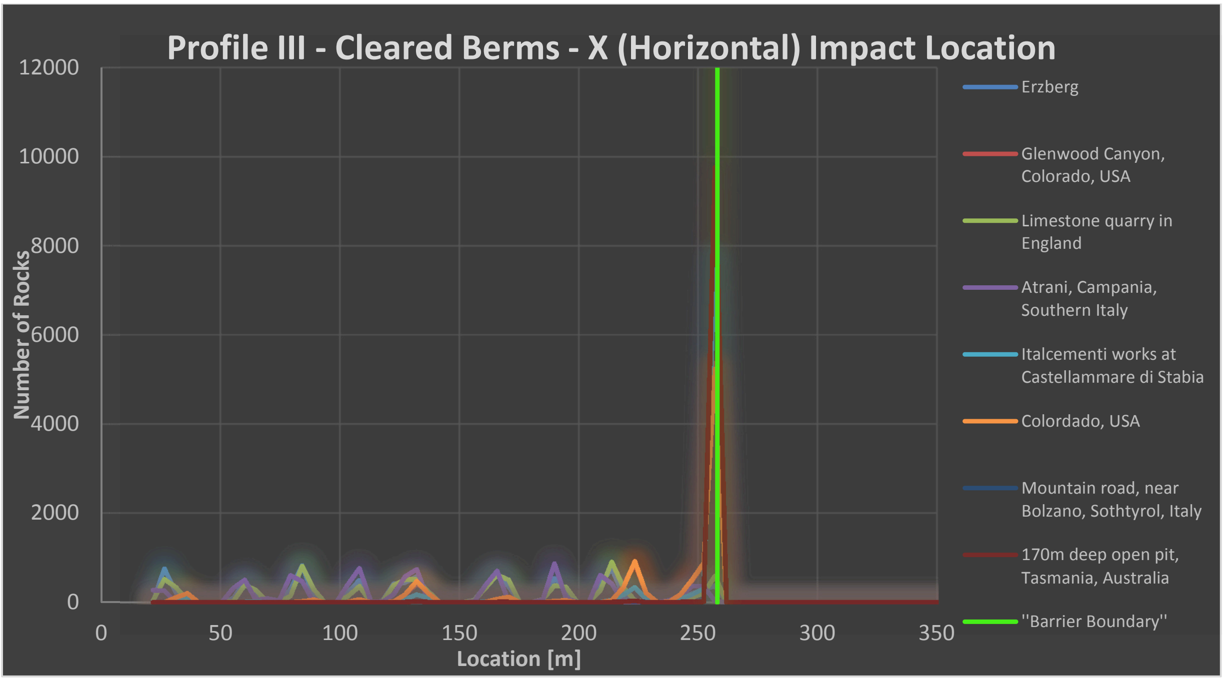

Figure 31: Profile III - Cleared Berms - X (Horizontal) Impact Location

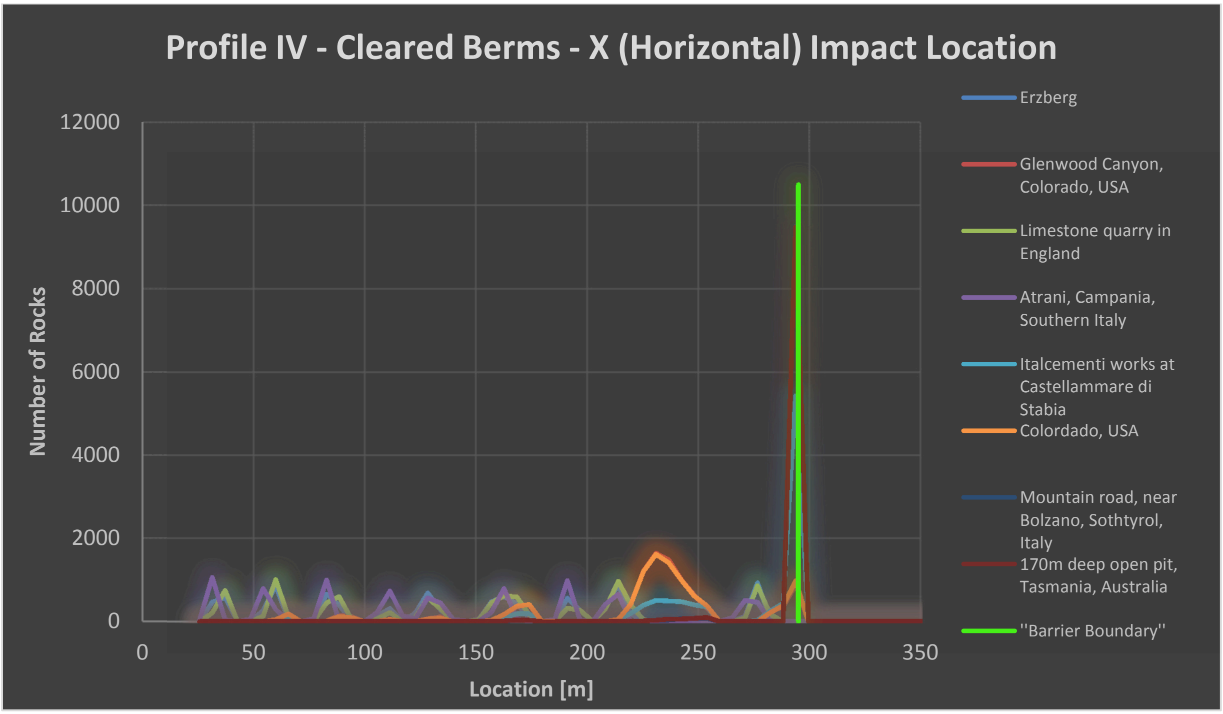

Figure 32: Profile IV - Cleared Berms - X (Horizontal) Impact Location

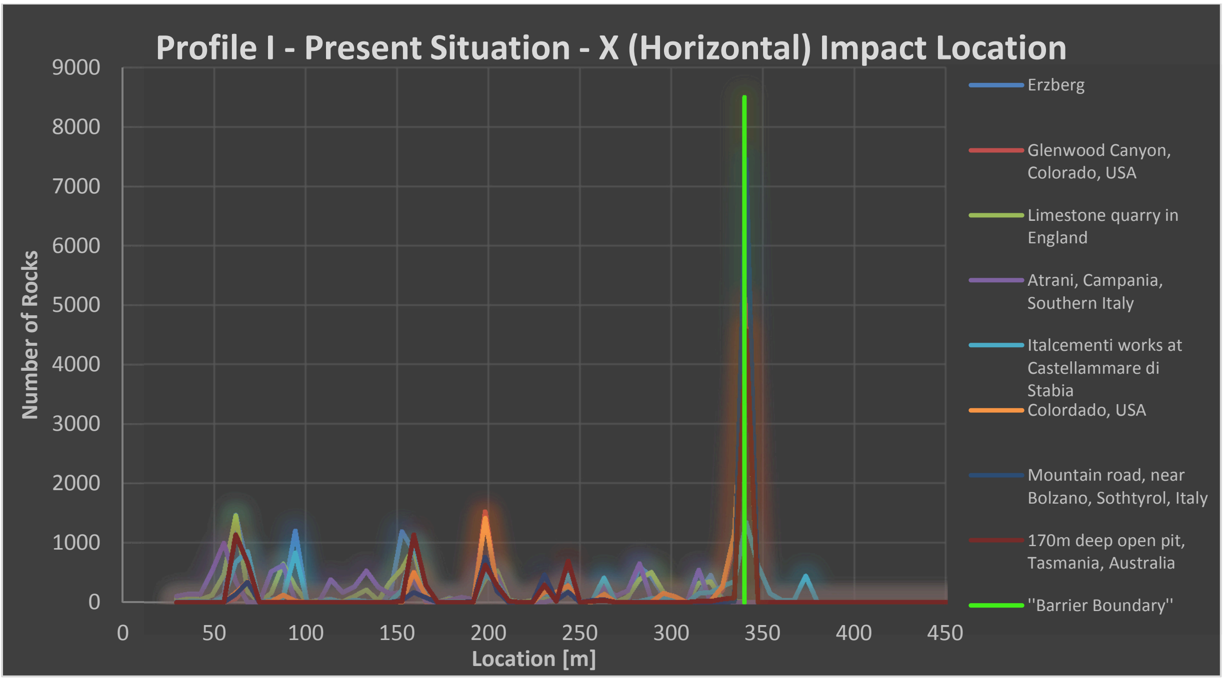

Figure 33: Profile I - Present Situation - X (Horizontal) Impact Location

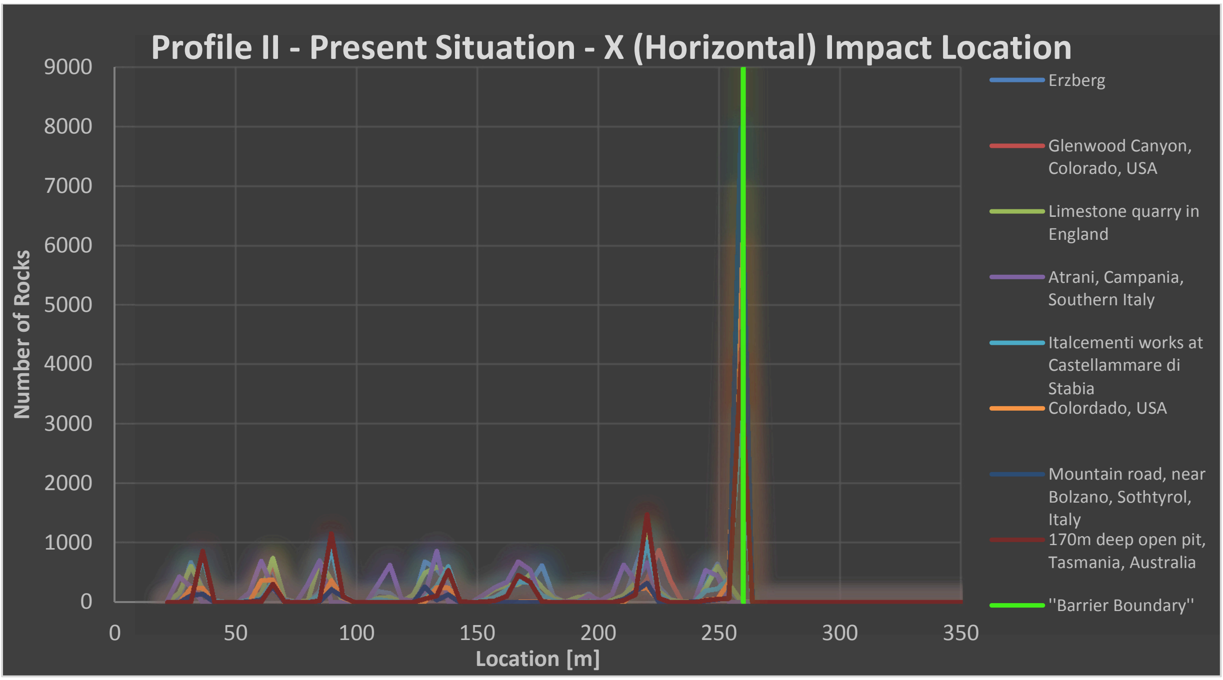

Figure 34: Profile II - Present Situation - X (Horizontal) Impact Location

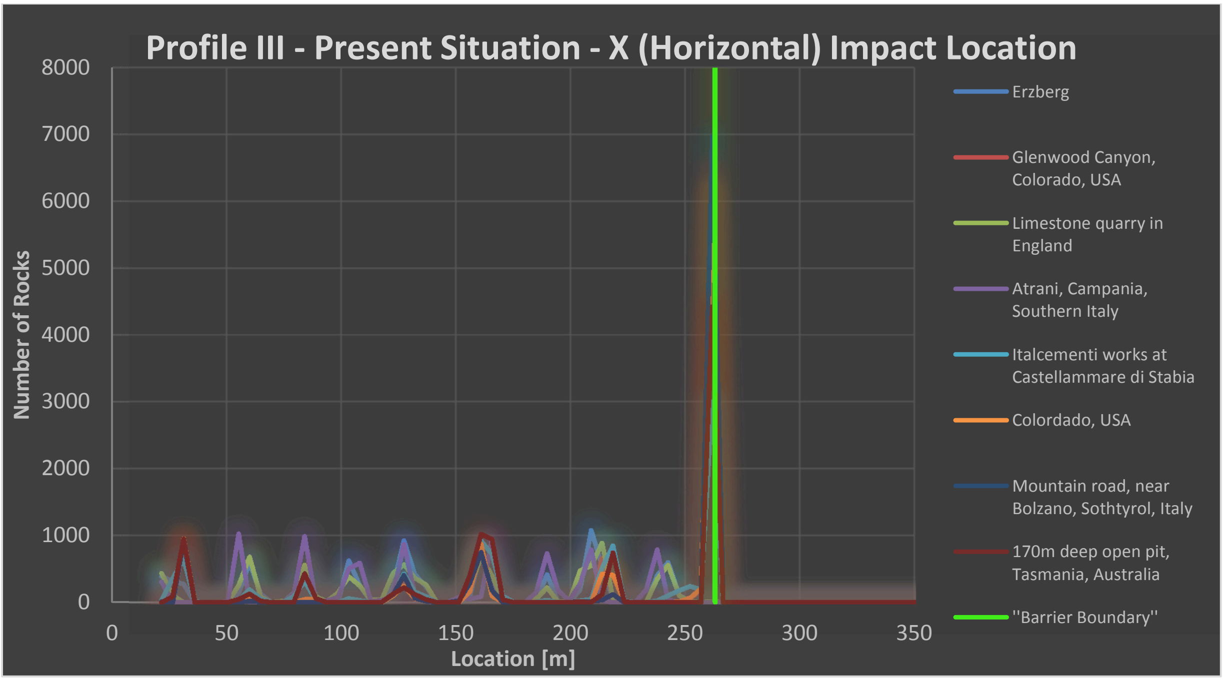

Figure 35: Profile III - Present Situation - X (Horizontal) Impact Location

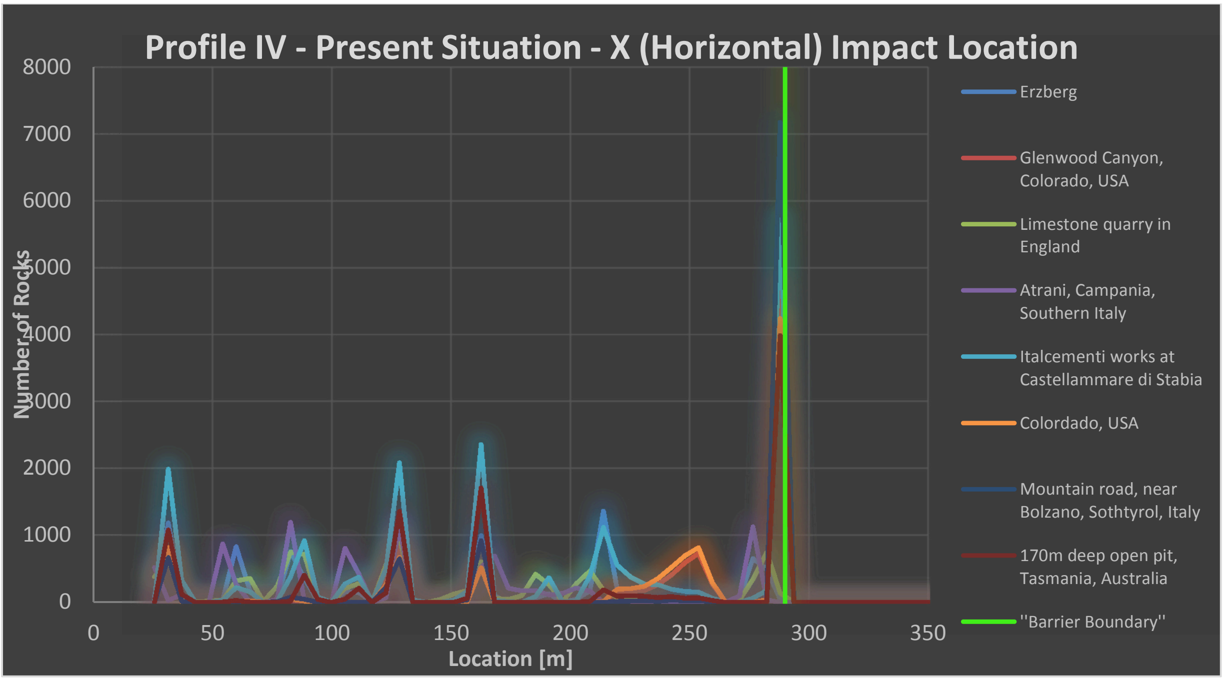

Figure 36: Profile IV - Present Situation - X (Horizontal) Impact Location

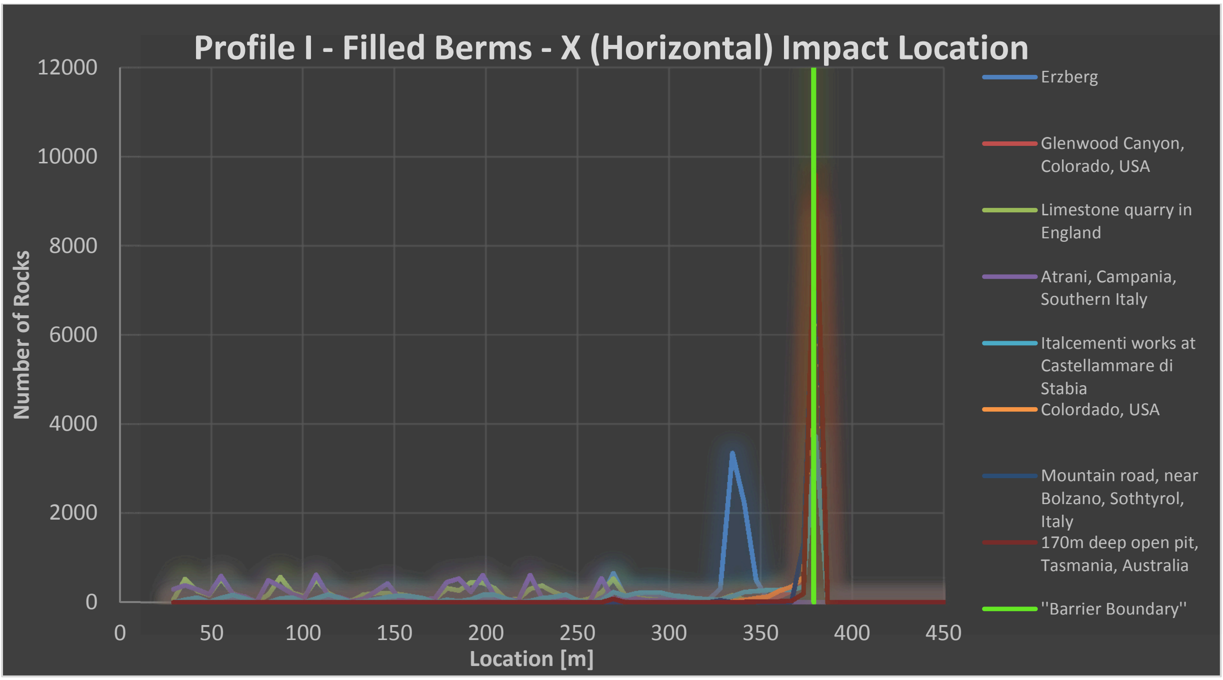

Figure 37: Profile I - Filled Berms - X (Horizontal) Impact Location

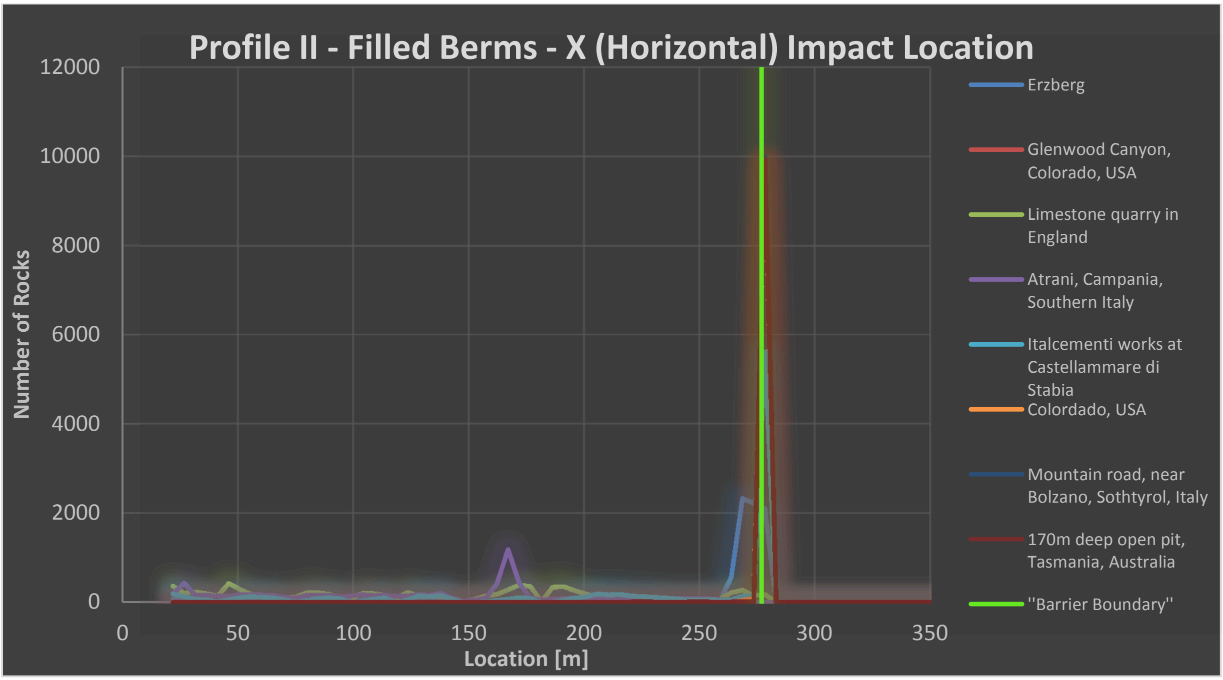

Figure 38: Profile II - Filled Berms - X (Horizontal) Impact Location

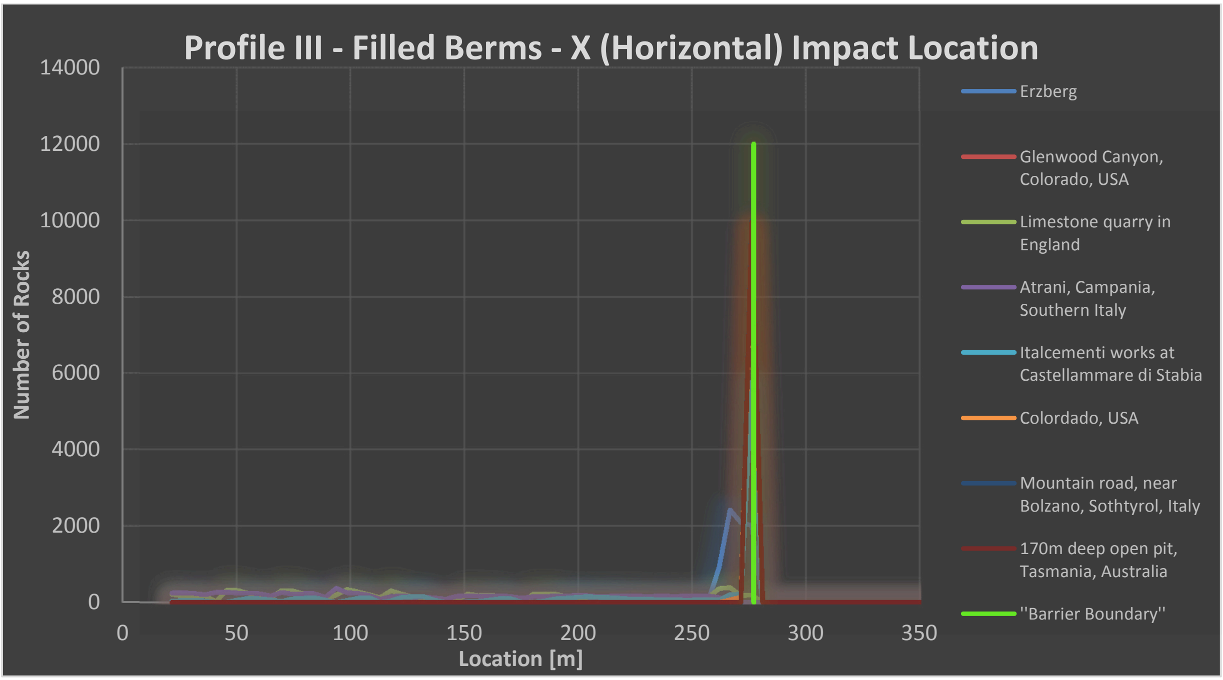

Figure 39: Profile III - Filled Berms - X (Horizontal) Impact Location

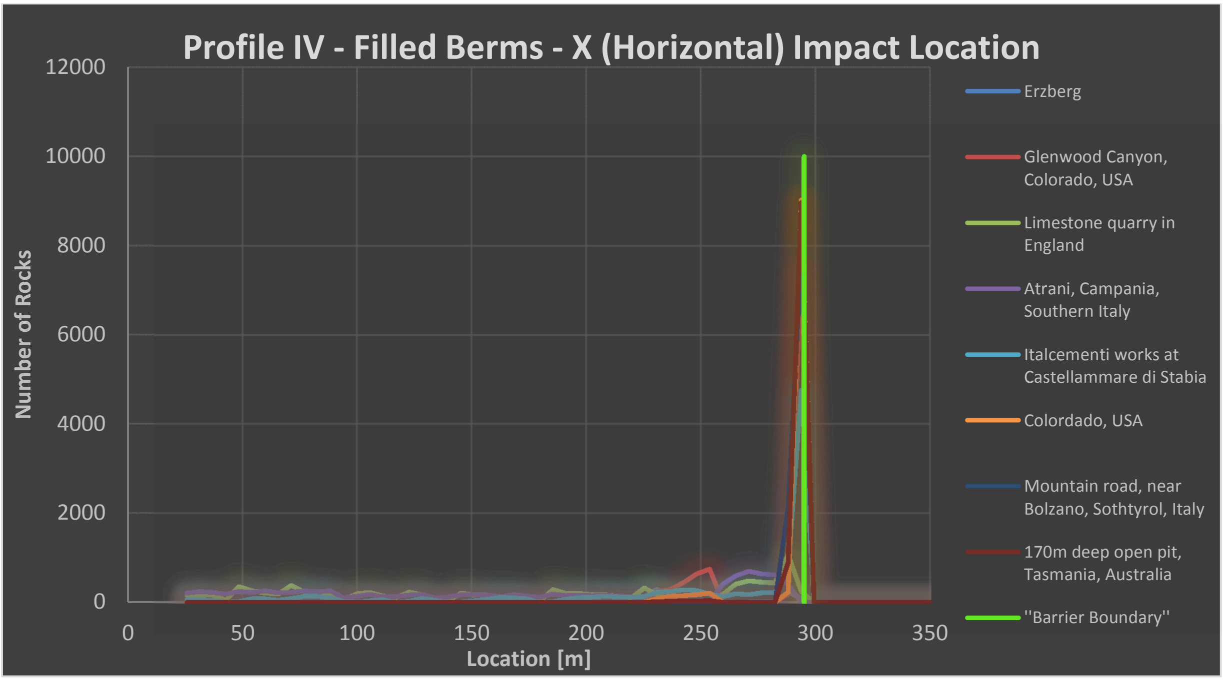

Figure 40: Profile IV - Filled Berms - X (Horizontal) Impact Location

Annex VI: Y (Vertical) Impact Locations on the Barrier

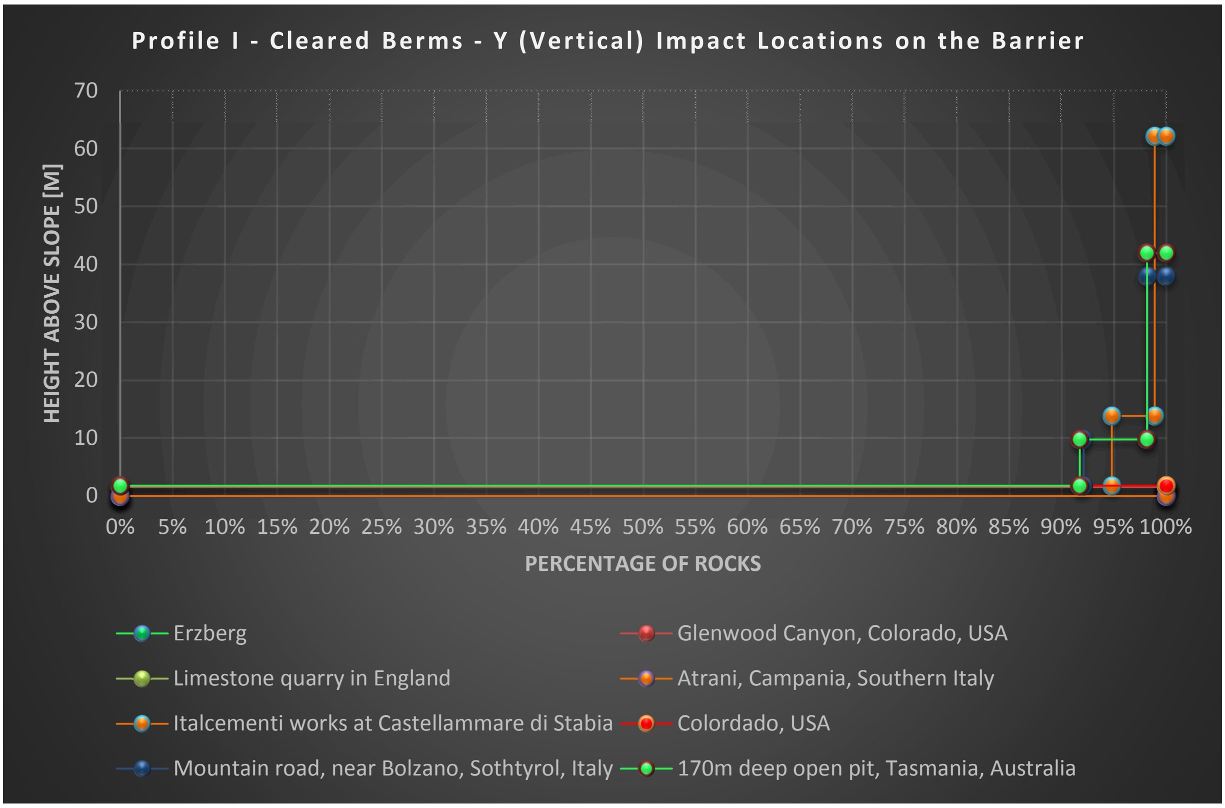

Figure 41: Profile I - Cleared Berms - Y (Vertical) Impact Locations on the Barrier

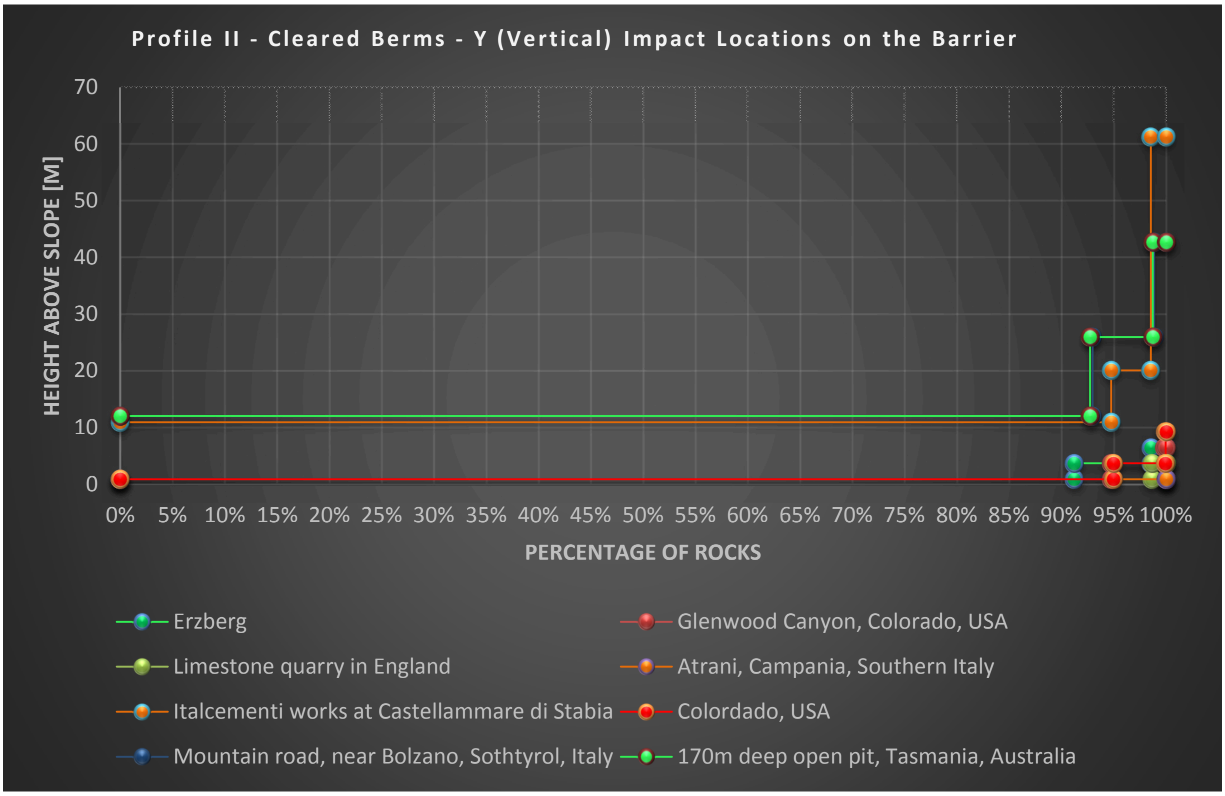

Figure 42: Profile II - Cleared Berms - Y (Vertical) Impact Locations on the Barrier

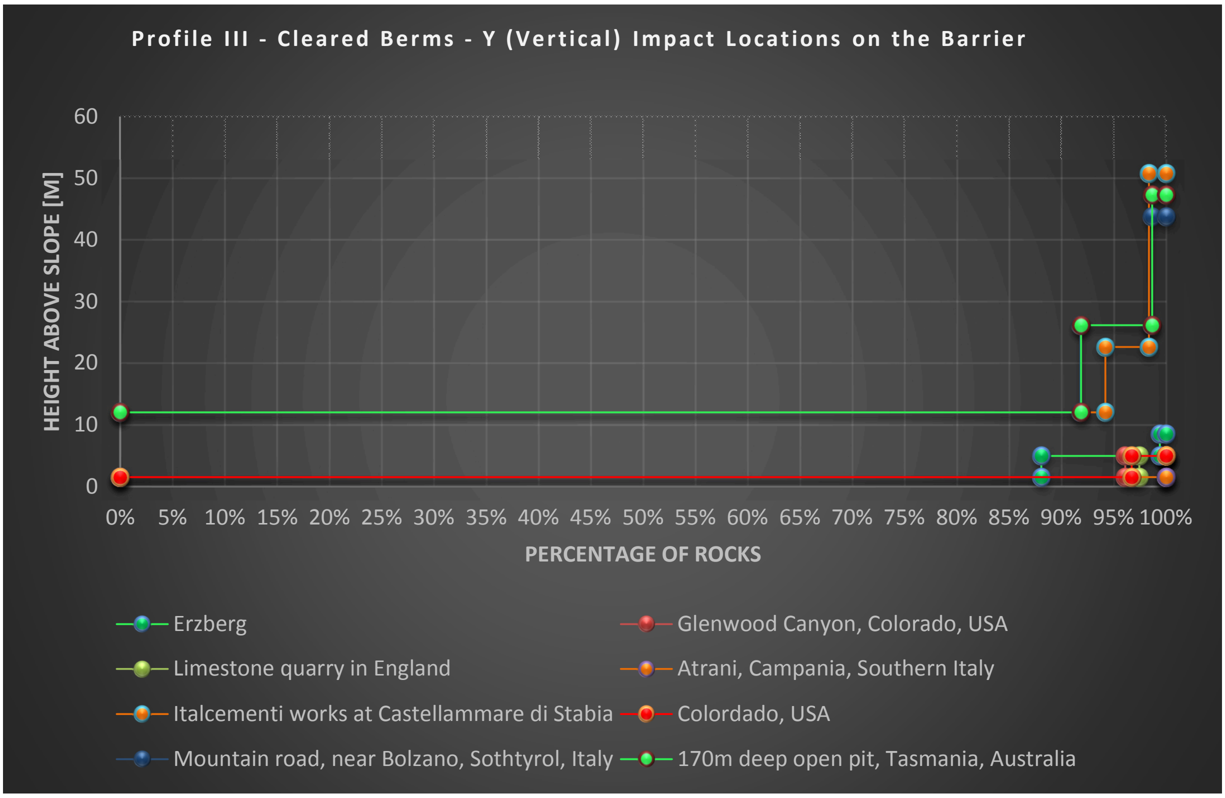

Figure 43: **Profile III - Cleared Berms - Y (Vertical) Impact Locations on the Barrier**

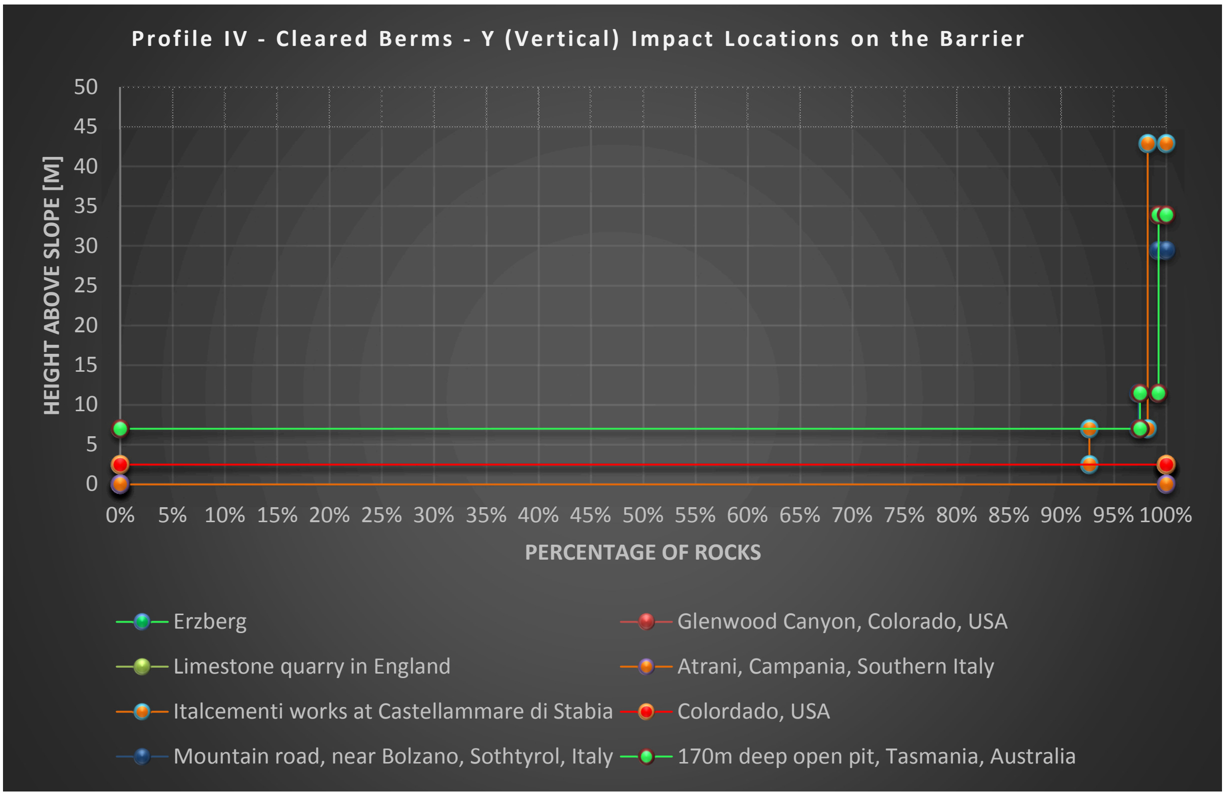

Figure 44: **Profile IV - Cleared Berms - Y (Vertical) Impact Locations on the Barrier**

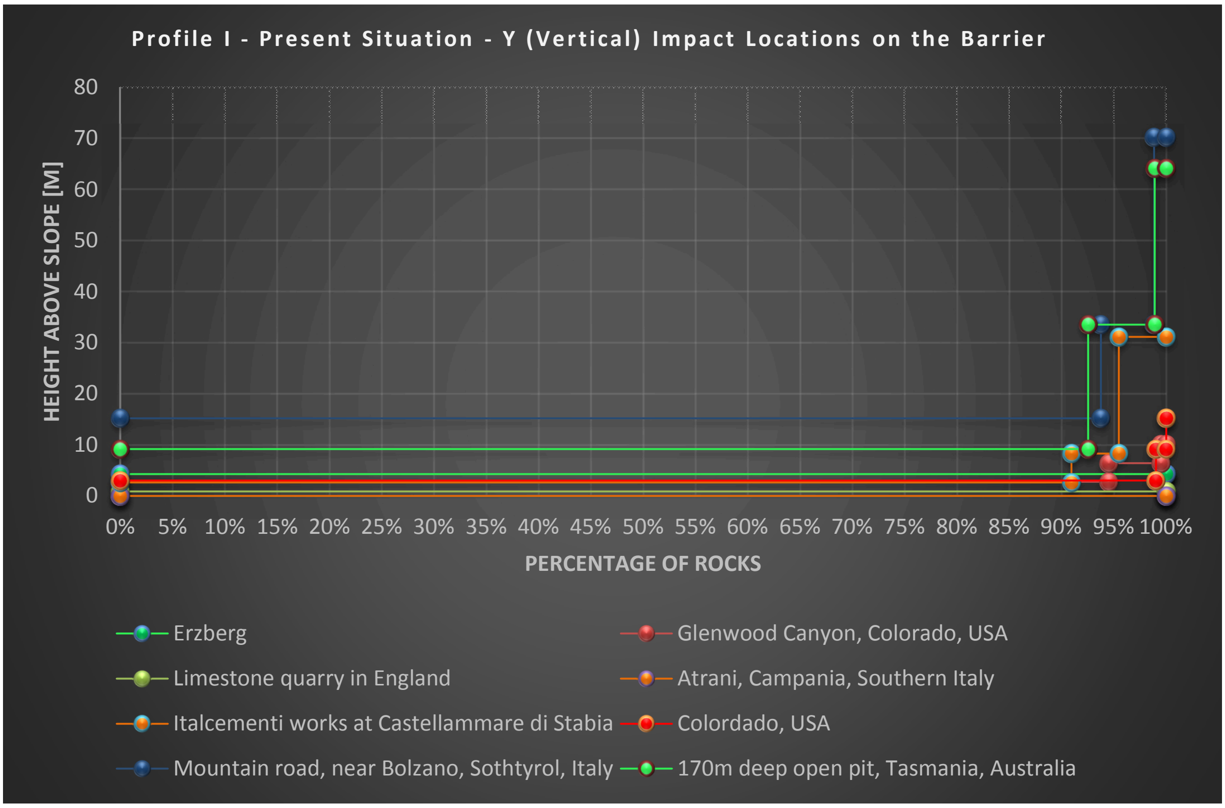

Figure 45: Profile I - Present Situation - Y (Vertical) Impact Locations on the Barrier

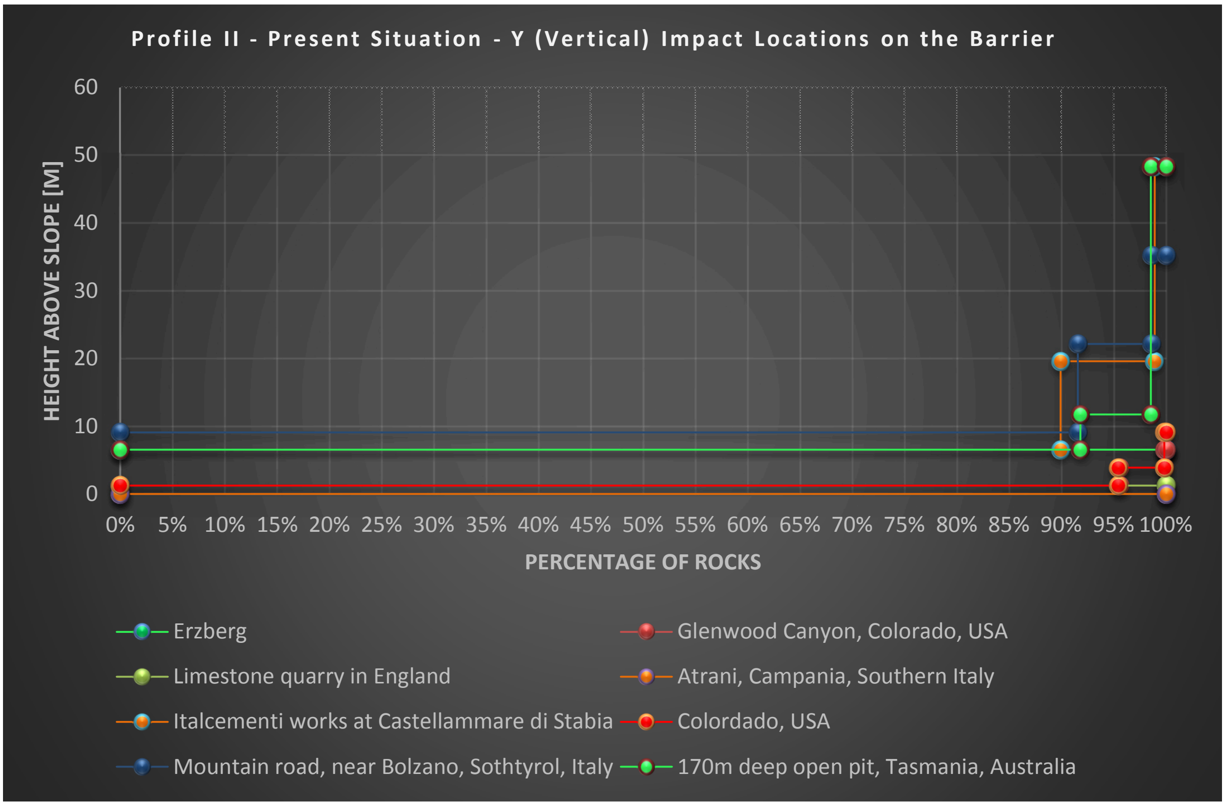

Figure 46: Profile II - Present Situation - Y (Vertical) Impact Locations on the Barrier

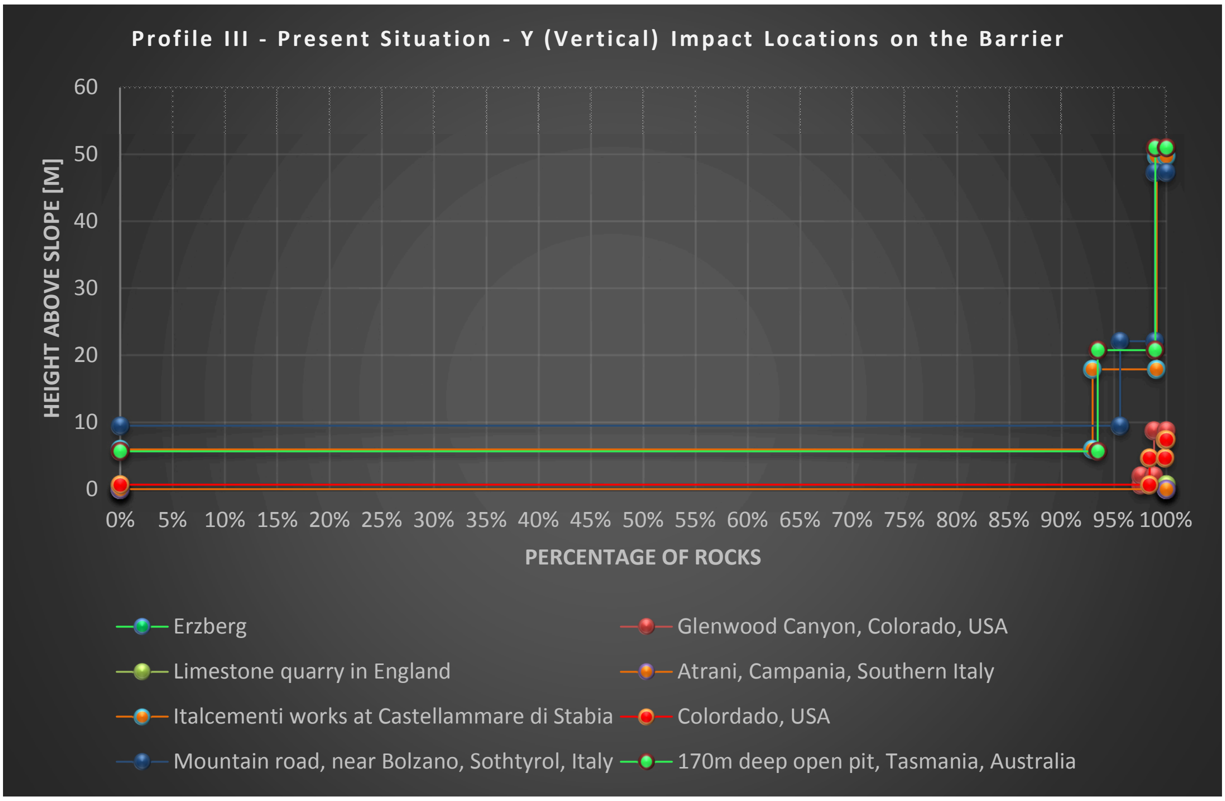

Figure 47: Profile III - Present Situation - Y (Vertical) Impact Locations on the Barrier

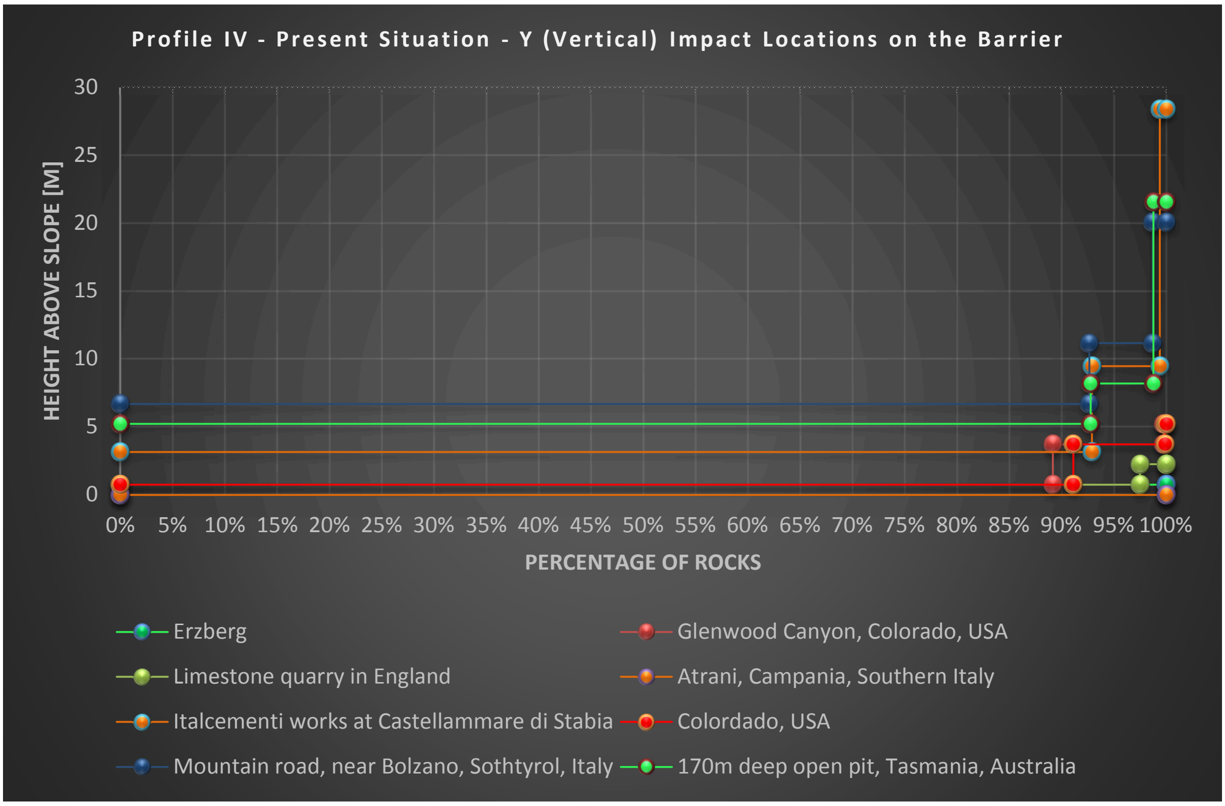

Figure 48: Profile IV - Present Situation - Y (Vertical) Impact Locations on the Barrier

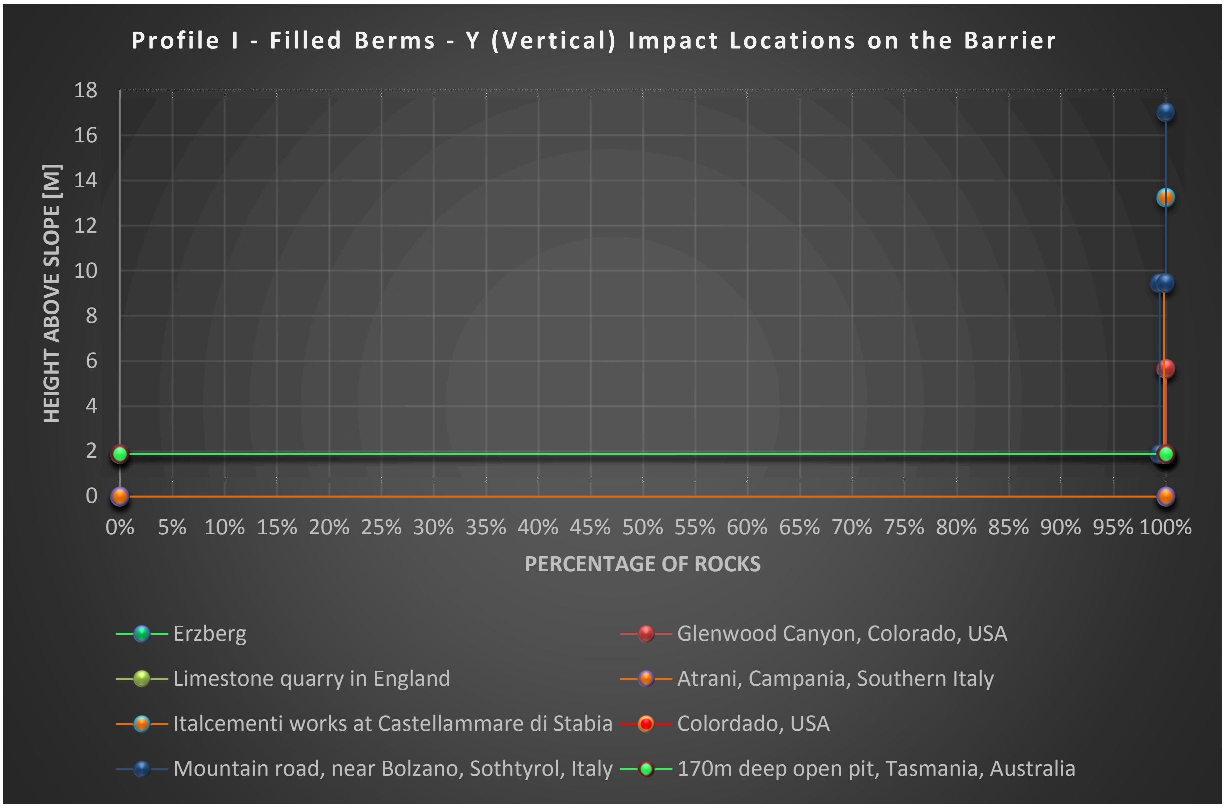

Figure 49: Profile I - Filled Berms - Y (Vertical) Impact Locations on the Barrier

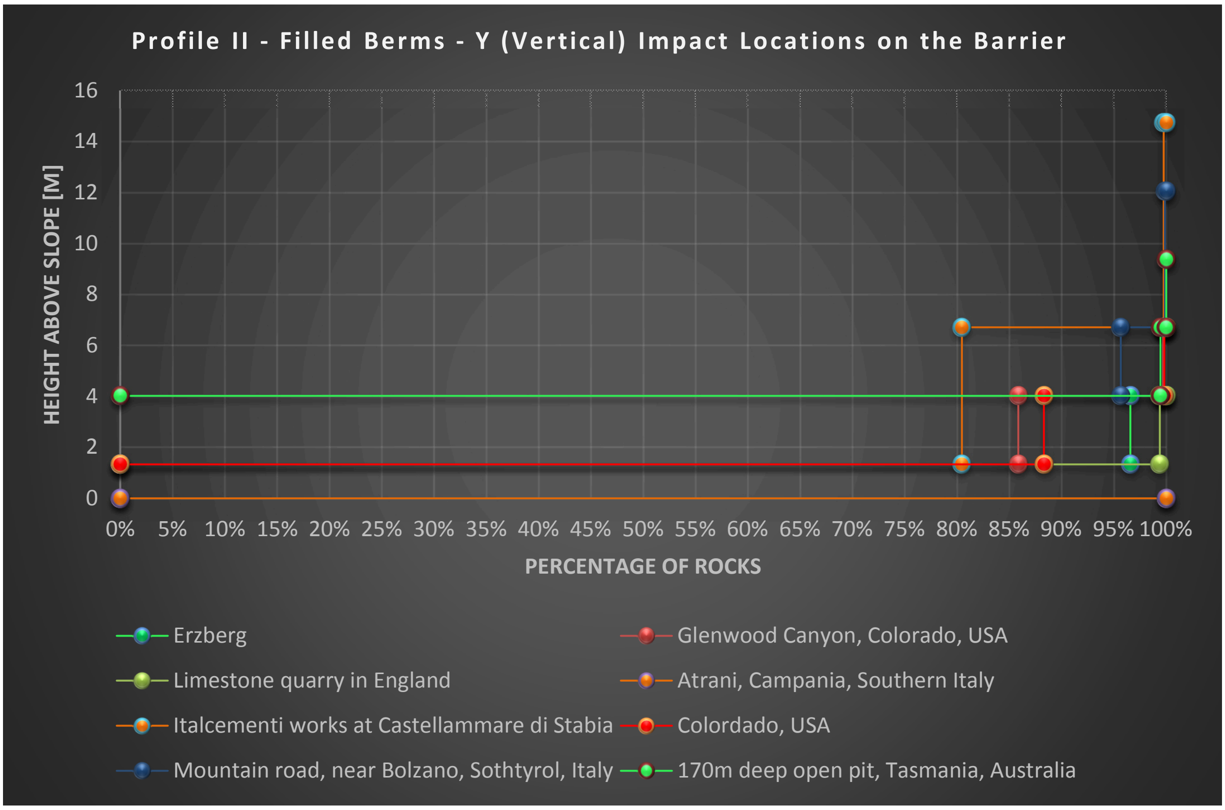

Figure 50: Profile II - Filled Berms - Y (Vertical) Impact Locations on the Barrier

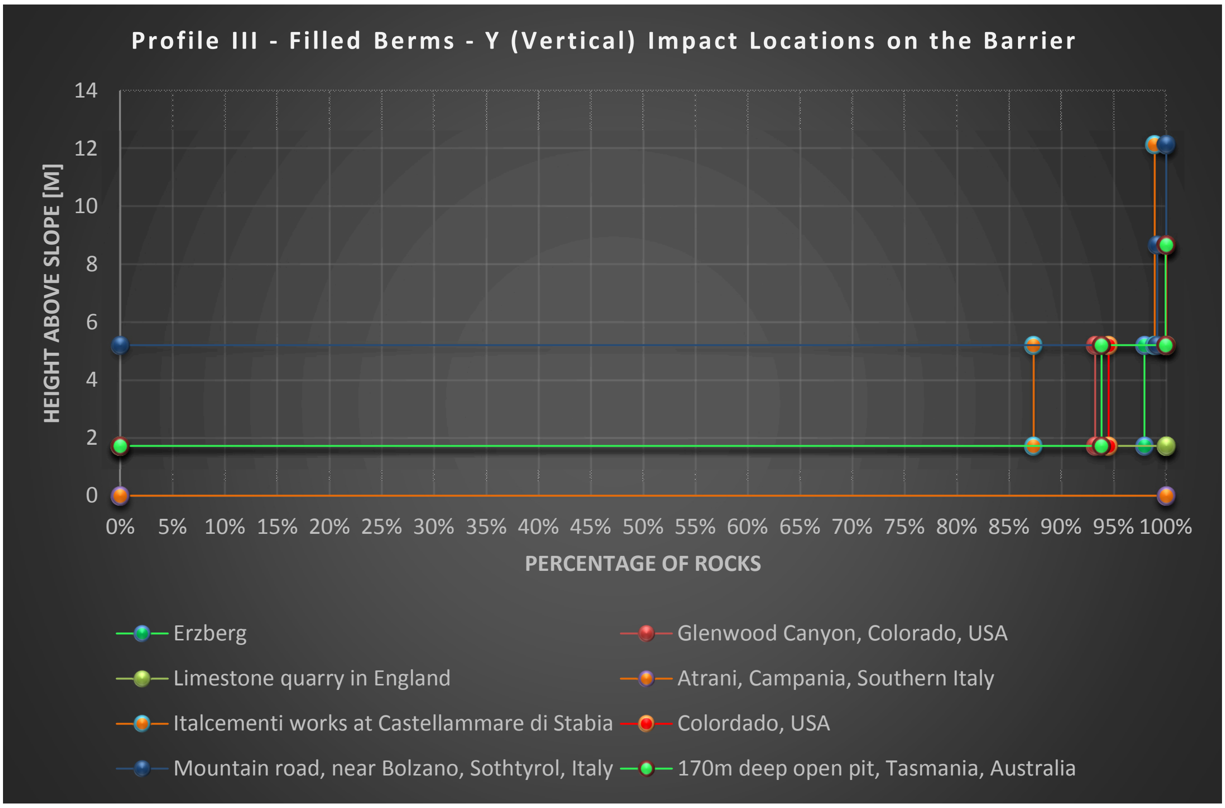

Figure 51: Profile III - Filled Berms - Y (Vertical) Impact Locations on the Barrier

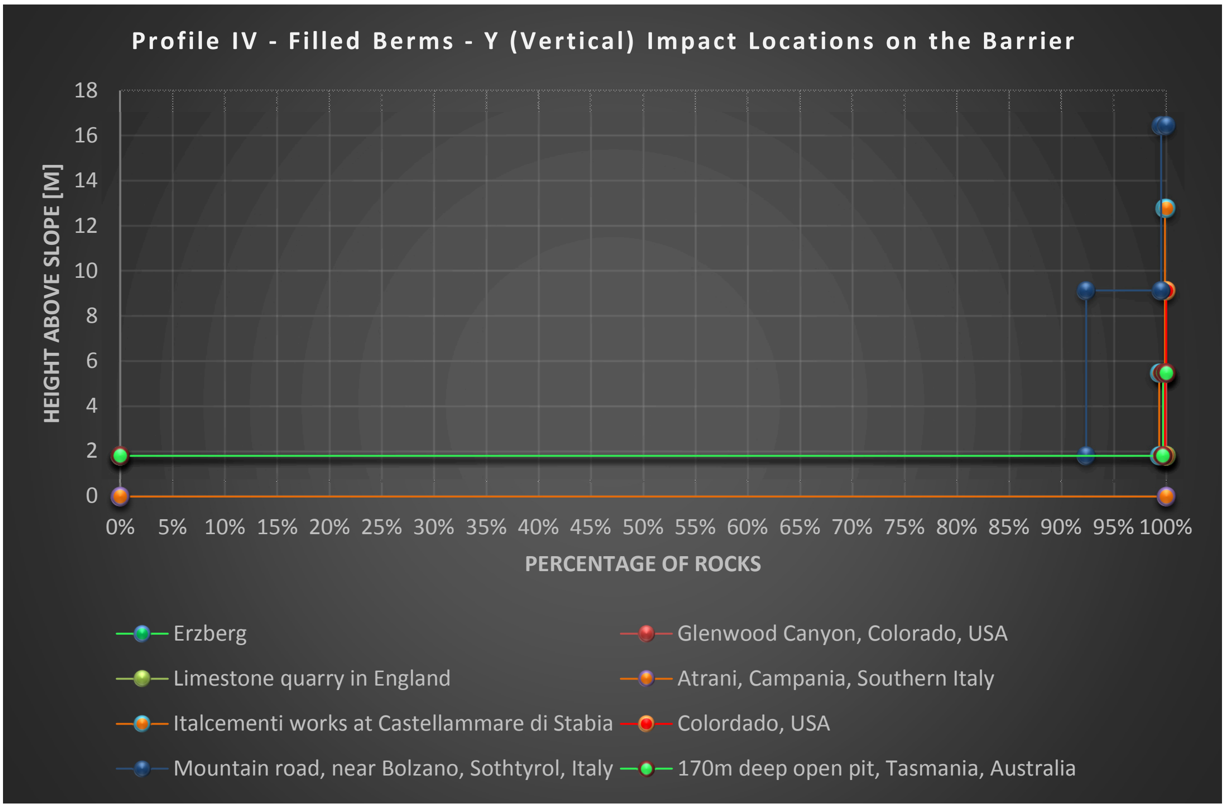

Figure 52: Profile IV - Filled Berms - Y (Vertical) Impact Locations on the Barrier

Annex VII: Total Kinetic Energy on Barrier

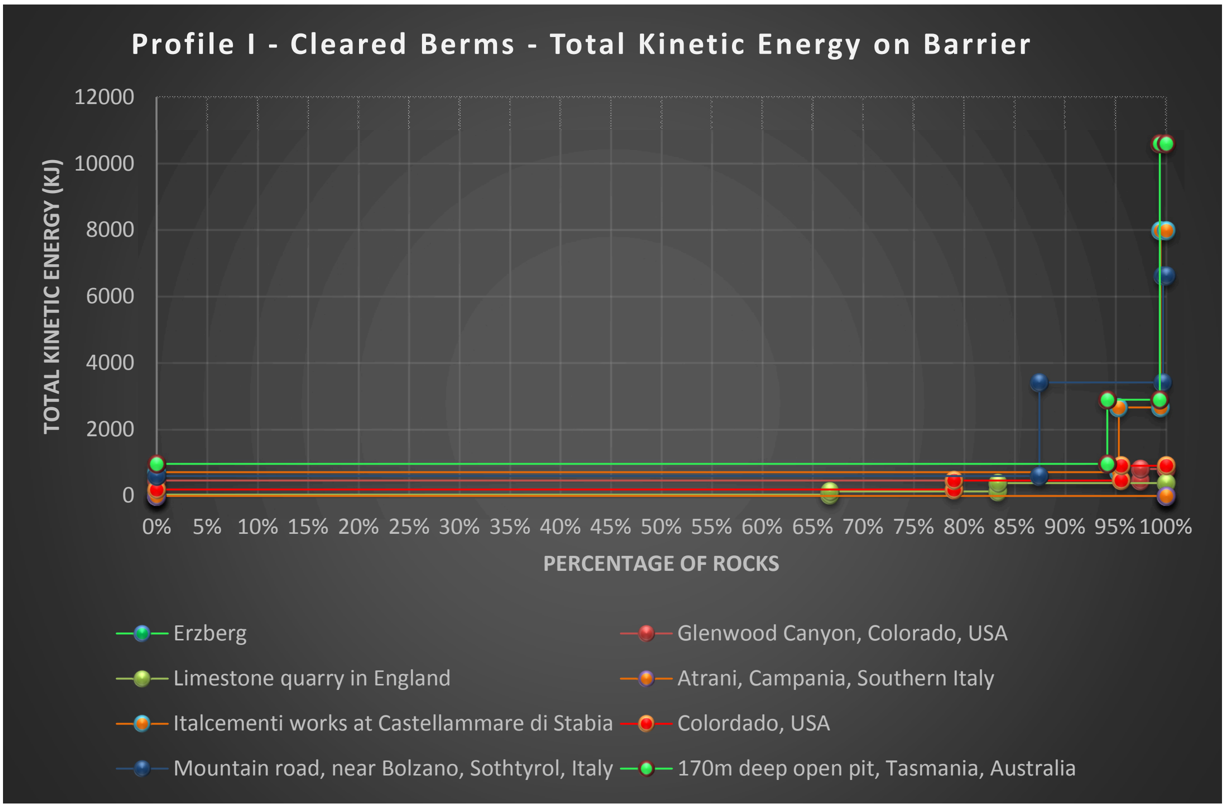

Figure 53: **Profile I - Cleared Berms - Total Kinetic Energy on Barrier**

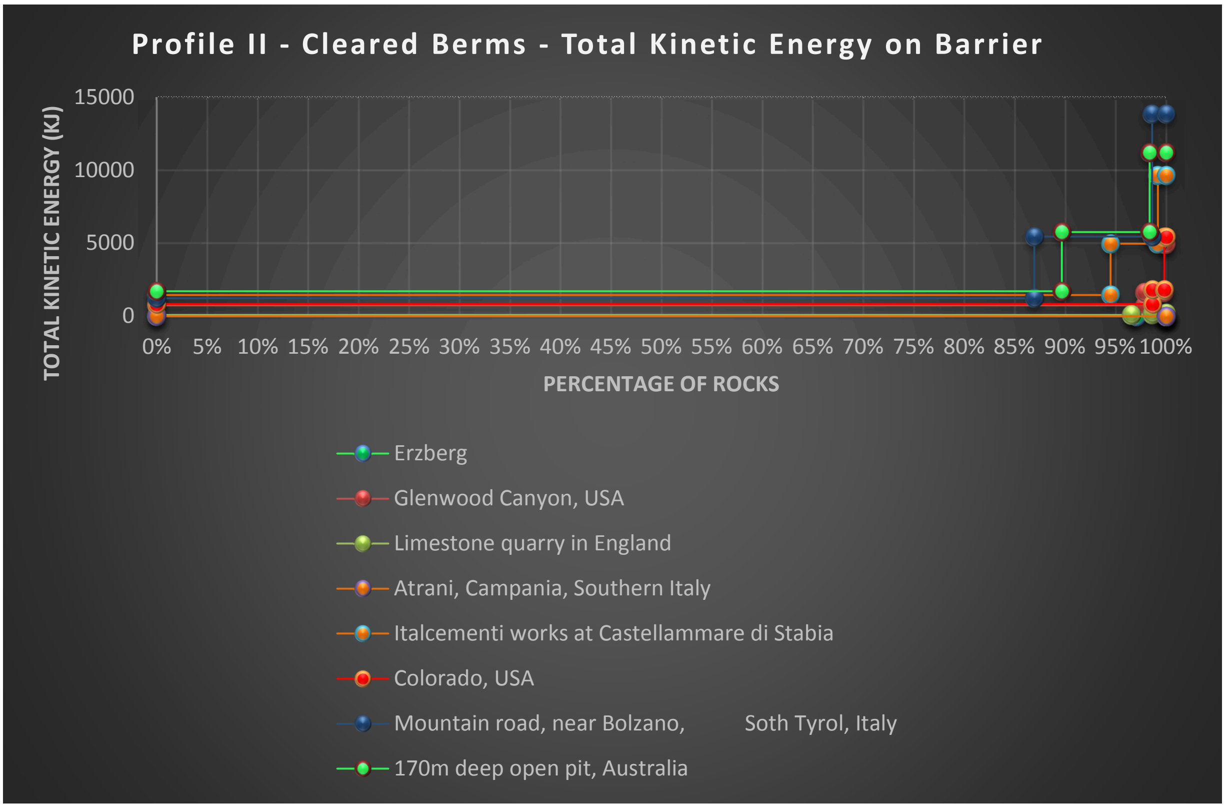

Figure 54: **Profile II - Cleared Berms - Total Kinetic Energy on Barrier**

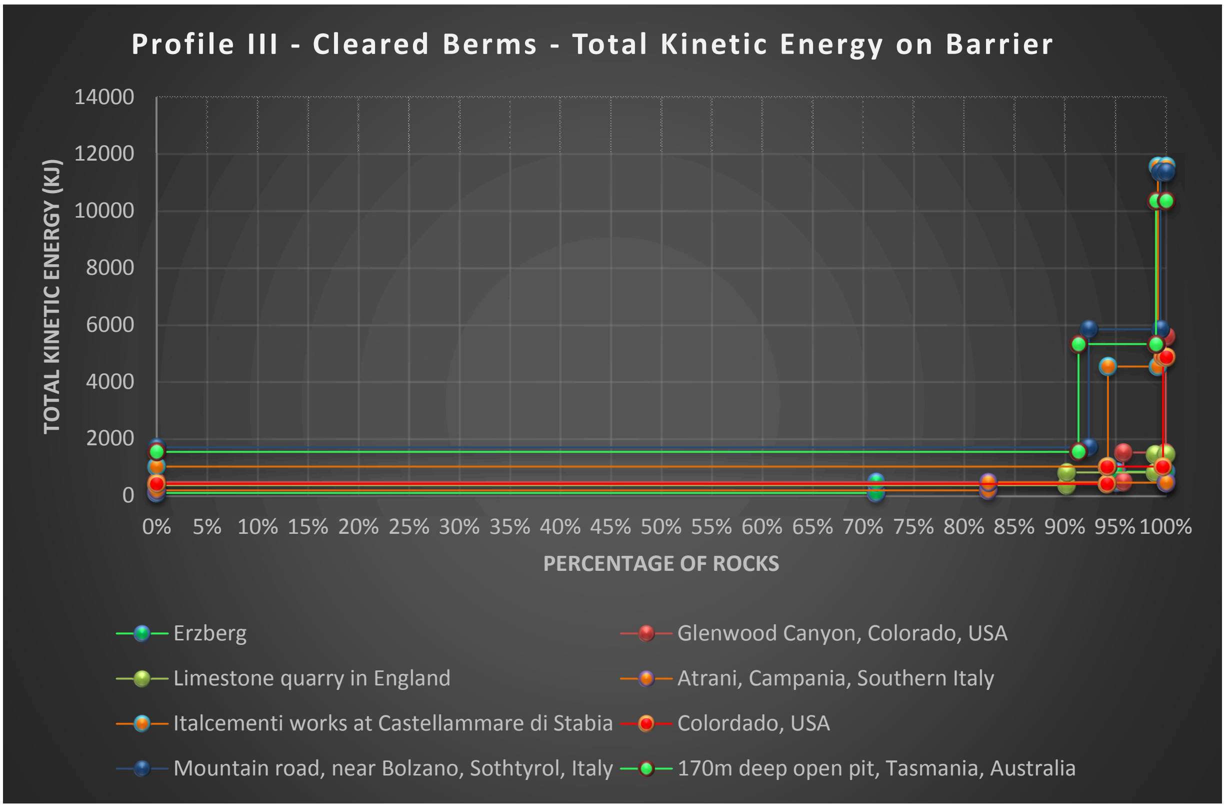

Figure 55: Profile III - Cleared Berms - Total Kinetic Energy on Barrier

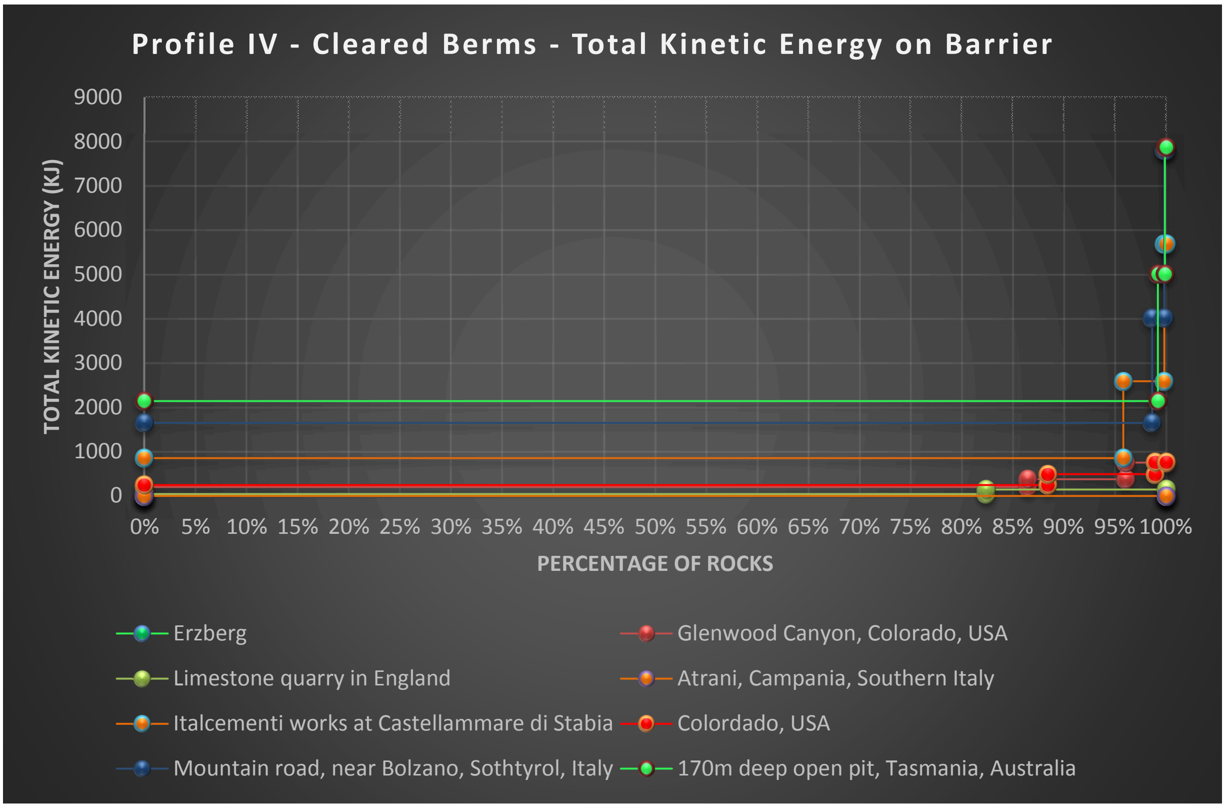

Figure 56: Profile IV - Cleared Berms - Total Kinetic Energy on Barrier

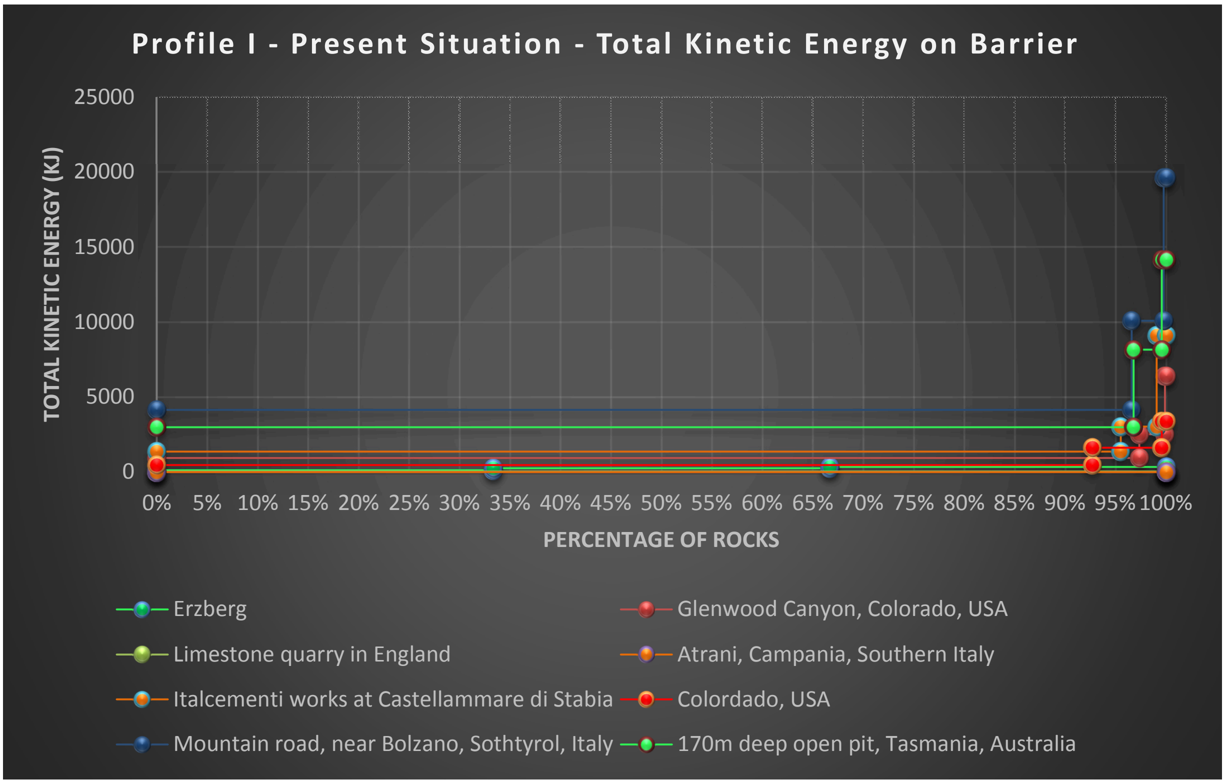

Figure 57: Profile I - Present Situation - Total Kinetic Energy on Barrier

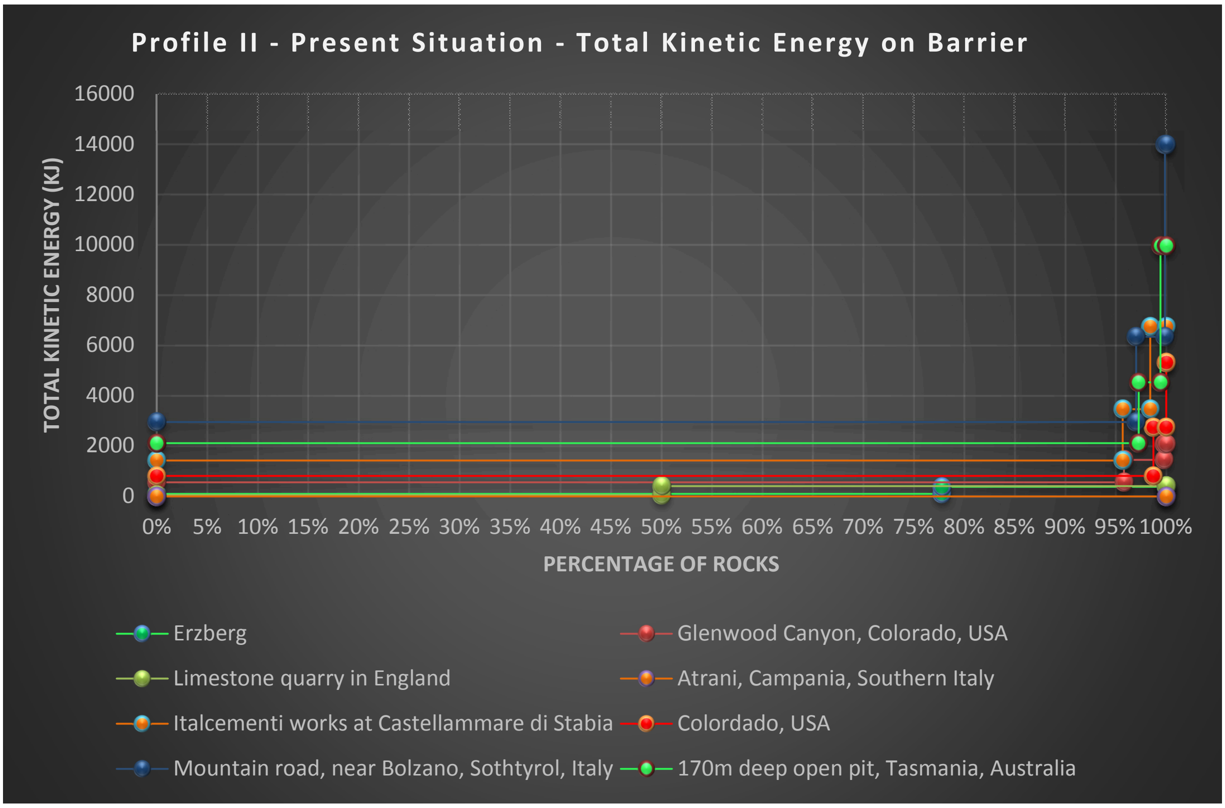

Figure 58: Profile II - Present Situation - Total Kinetic Energy on Barrier

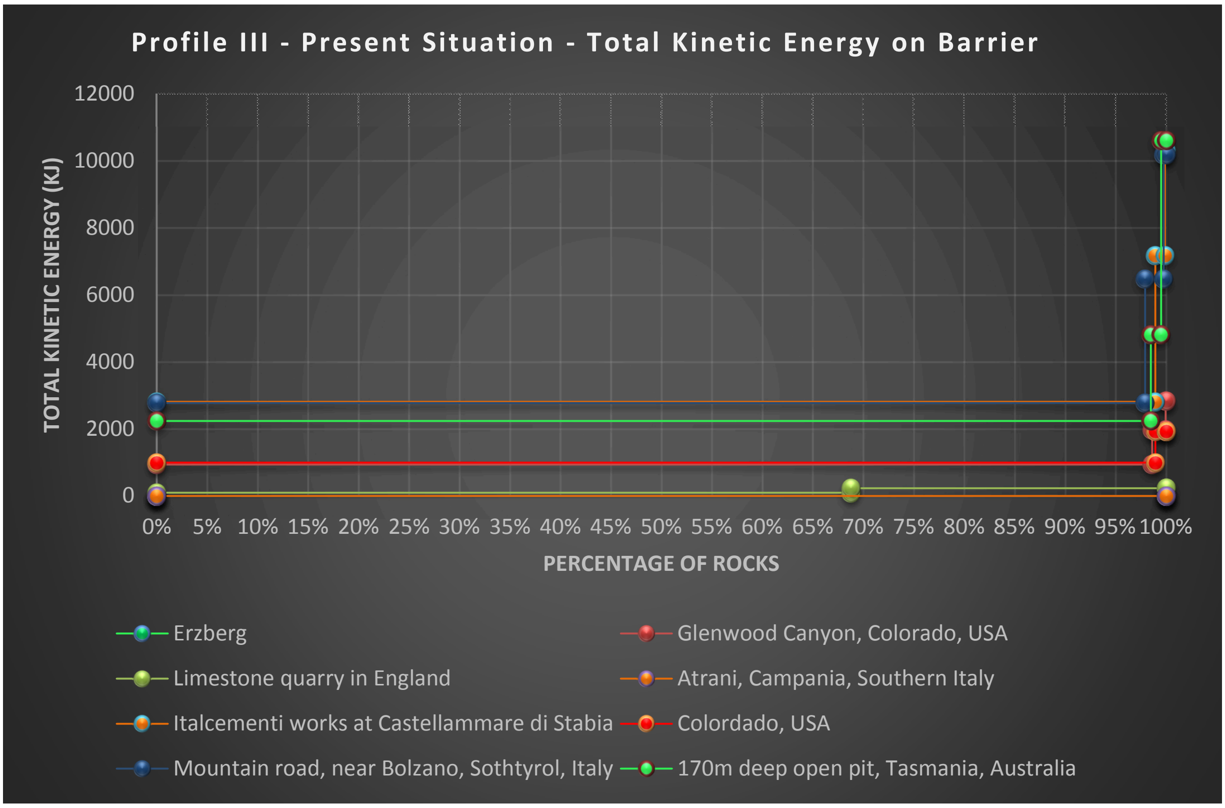

Figure 59: Profile III - Present Situation - Total Kinetic Energy on Barrier

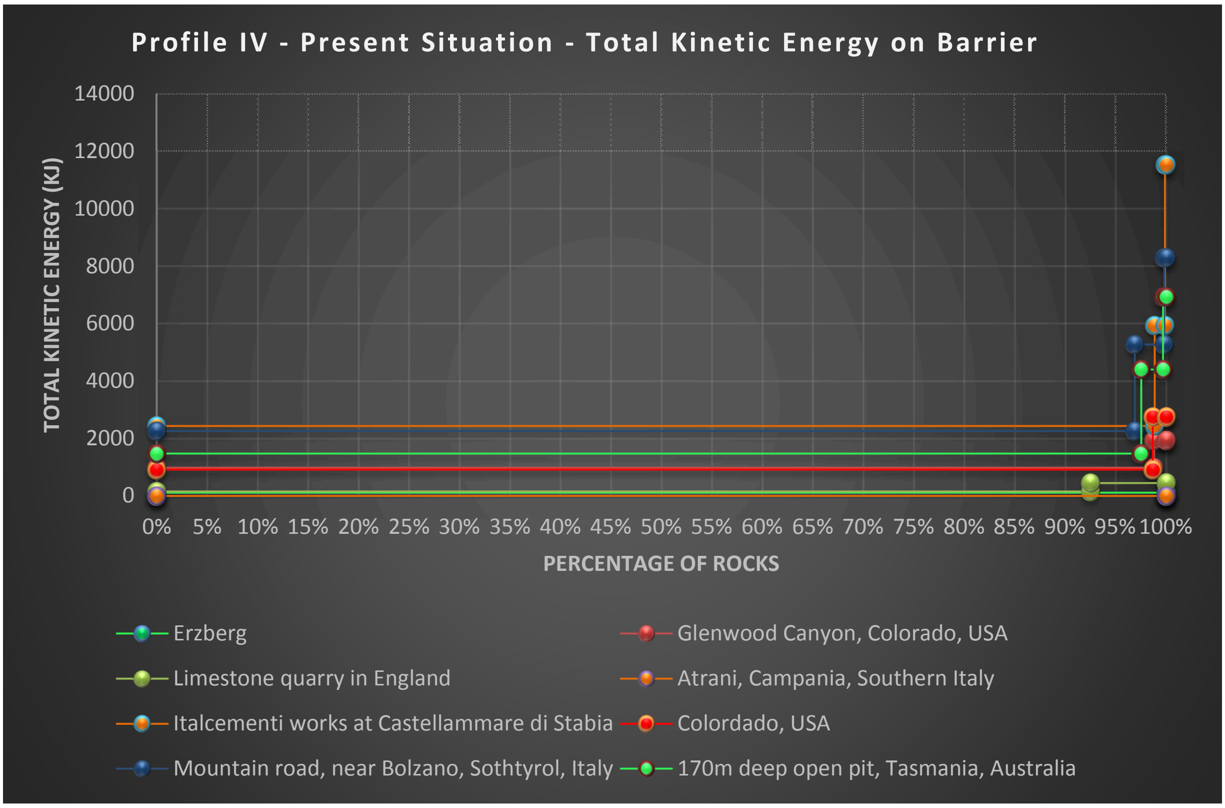

Figure 60: Profile IV - Present Situation - Total Kinetic Energy on Barrier

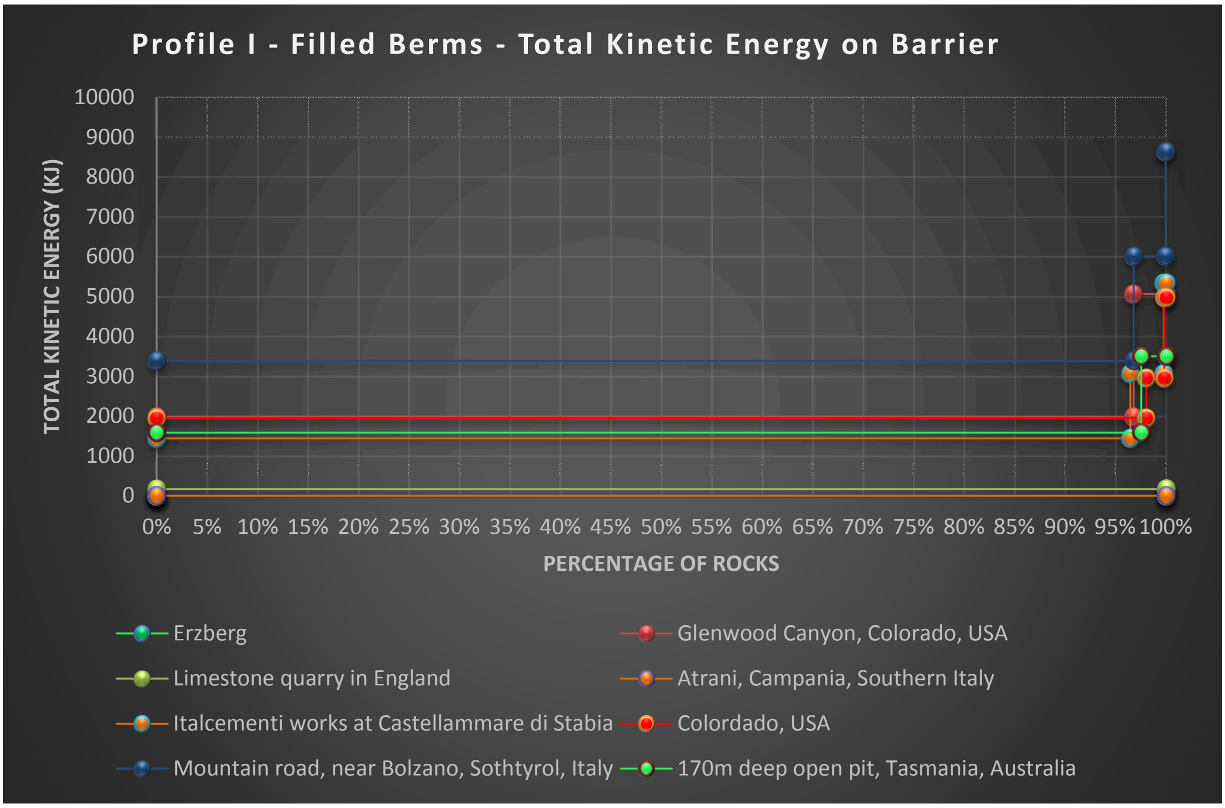

Figure 61: **Profile I - Filled Berms - Total Kinetic Energy on Barrier**

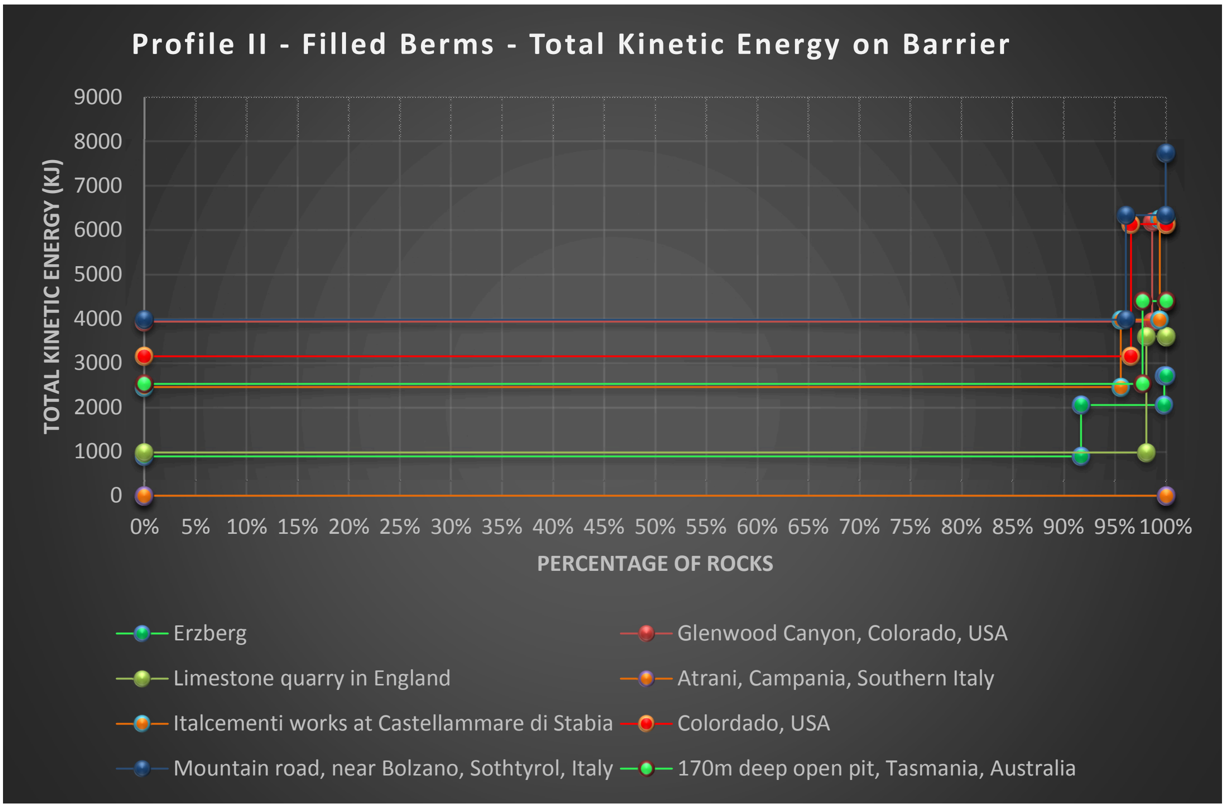

Figure 62: **Profile II - Filled Berms - Total Kinetic Energy on Barrier**

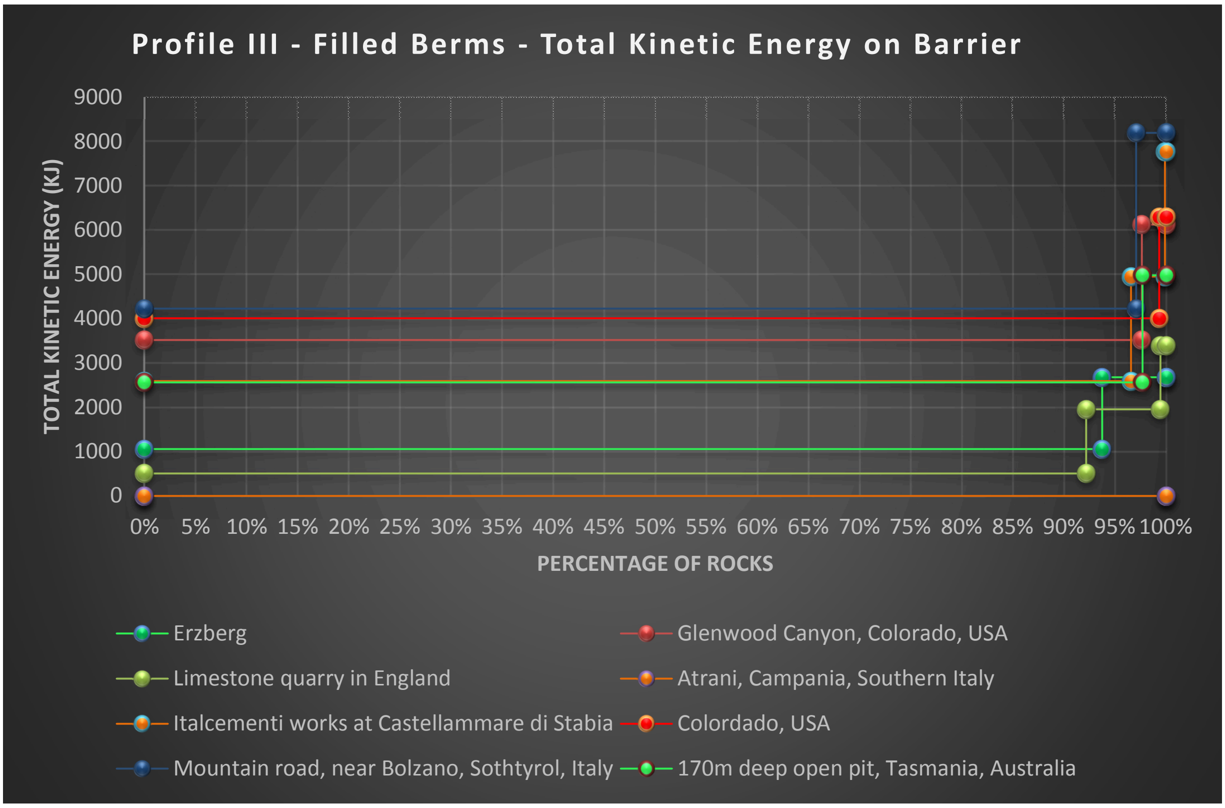

Figure 63: **Profile III - Filled Berms - Total Kinetic Energy on Barrier**

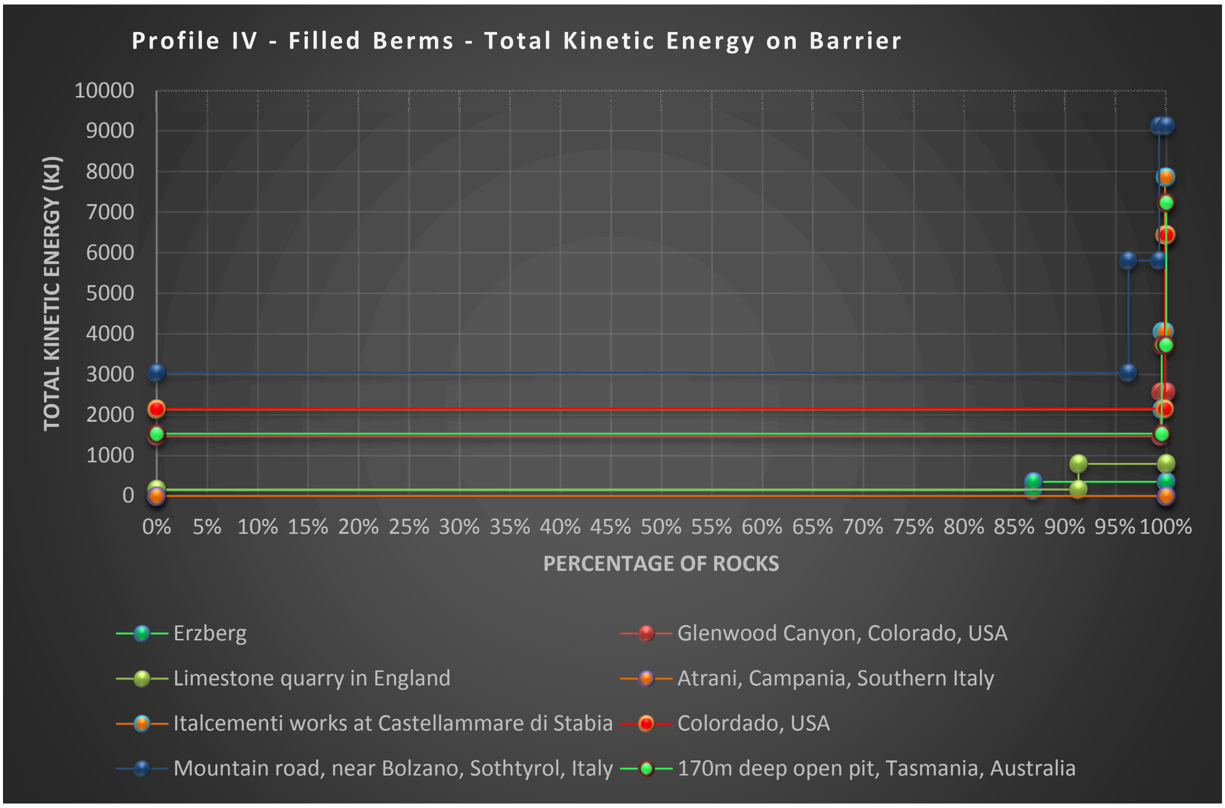

Figure 64: **Profile IV - Filled Berms - Total Kinetic Energy on Barrier**