NATURAL RI$K EVALUATION

**INTERNATIONAL WORKSHOP**

# An approach to rockfall risk calculation: the RO.MA Method

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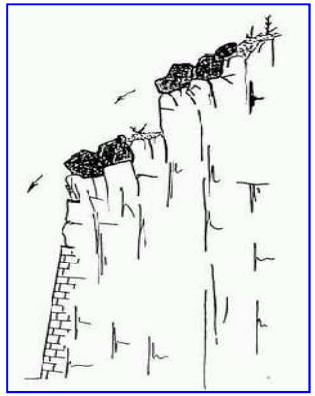
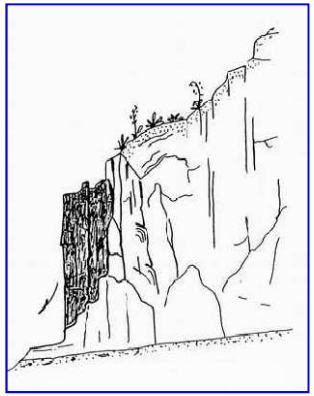
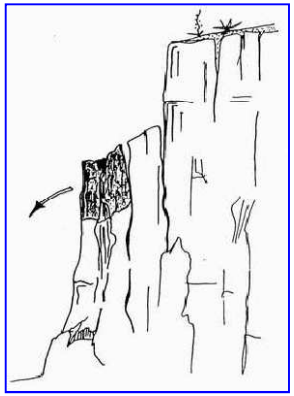
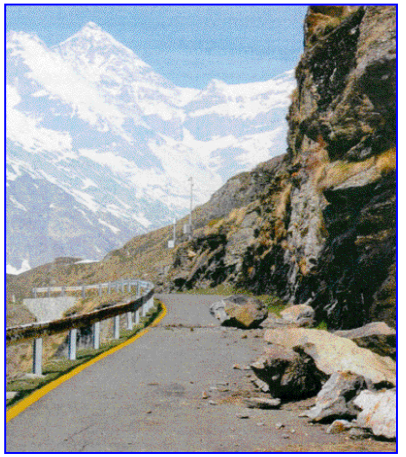
# *Introduction*

Rockfall from steep cliffs frequently occur in mountain regions and are a constant source of danger to life, property and human activities, in areas generally very active in terms of tourism and cause the closure of major roads

This study focuses on the problem of rockfalls that interfere with road infrastructures and on the connected risk evaluation



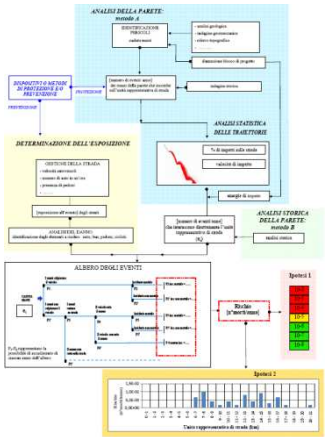
**Goal** : provide a simple tool to quantify rockfall risks for roads

The method refers to the risk assessment processes usually used in the management of industrial plants, land-use planning and work safety

The logical calculus process consists of a series of interacting macrophases to assess the risk to which a road is subjected

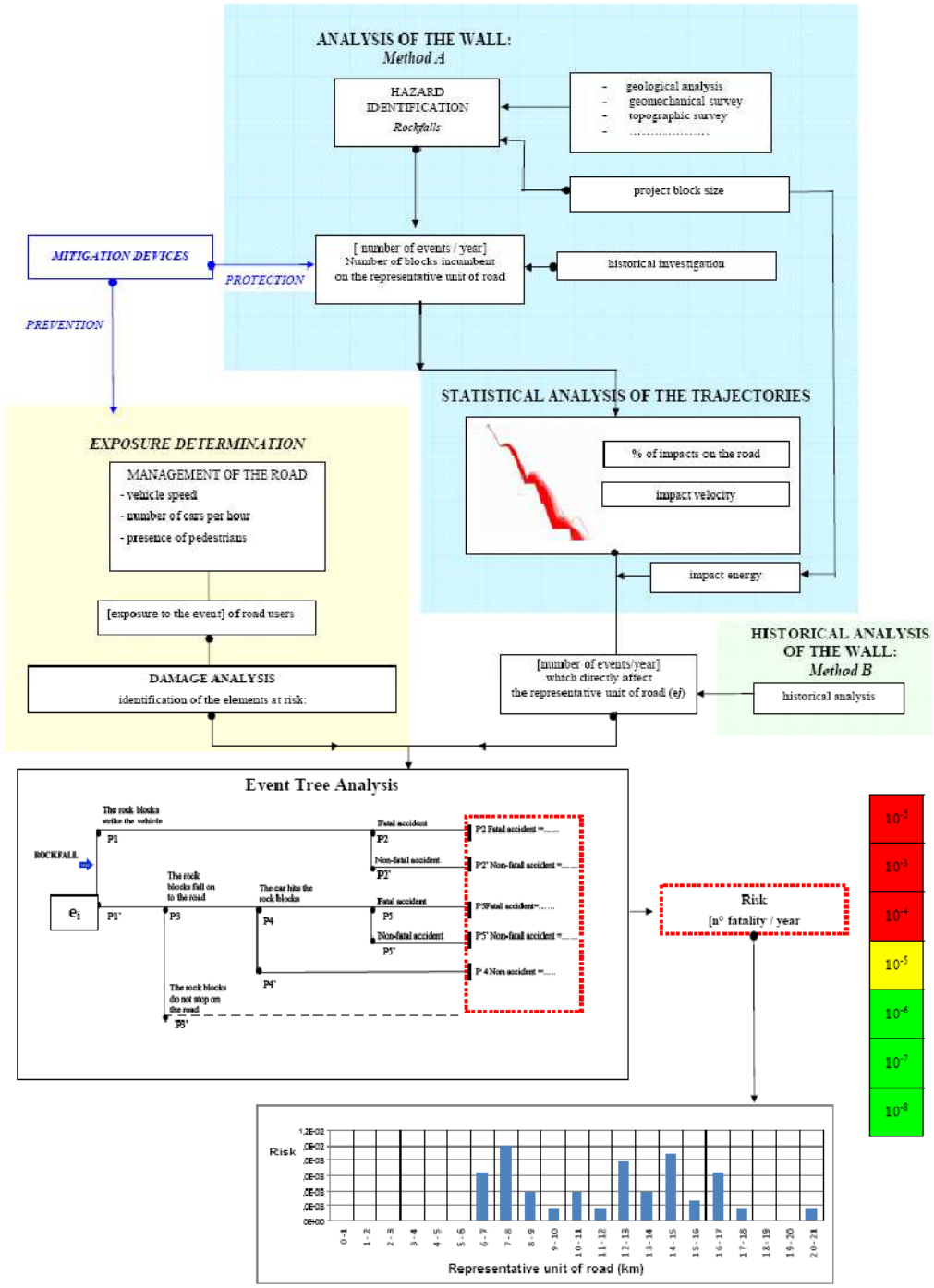
## Main features of RO.MA.

- it offers a numerical risk value;
- the analysis can be repeated considering the evolution in time;
- it is based on the Event Tree Analysis;
- it considers the presence of protective structures and their efficiency



# *RO.MA.*

## *ROckfall risk MAnagement*



# *RO.MA. ROckfall risk MAnagement*

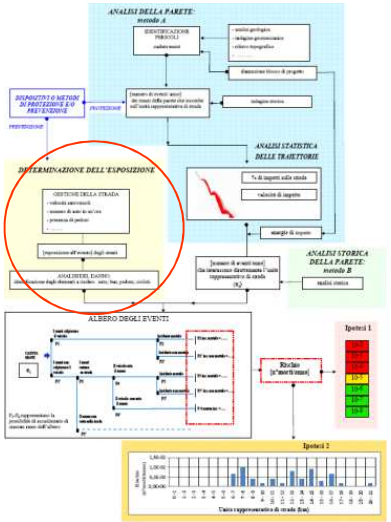
## *EXPOSURE DETERMINATION*

MANAGEMENT OF THE ROAD

- vehicle speed
- number of cars per hour
- presence of pedestrians

[exposure to the event] of road users

**DAMAGE ANALYSIS**
identification of the elements at risk:
cars, buses, pedestrians, cyclists



# *RO.MA. ROckfall risk MAnagement*

**ANALYSIS OF THE WALL: *Method A***

HAZARD IDENTIFICATION

*Rockfalls*

- geological analysis
- geomechanical survey
- topographic survey
- ……

project block size

historical investigation

[number of events/year]
Number of blocks incumbent on the representative unit of road

**HISTORICAL ANALYSIS OF THE WALL: *Method B***

historical analysis

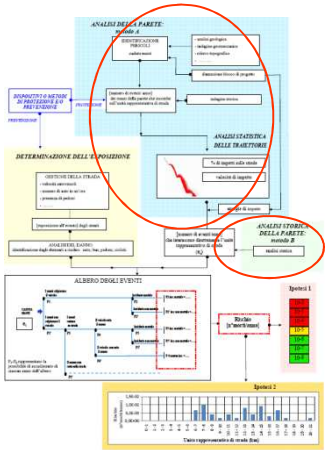
STATISTICAL ANALYSIS OF THE TRAJECTORIES

% of impacts on the road

impact velocity

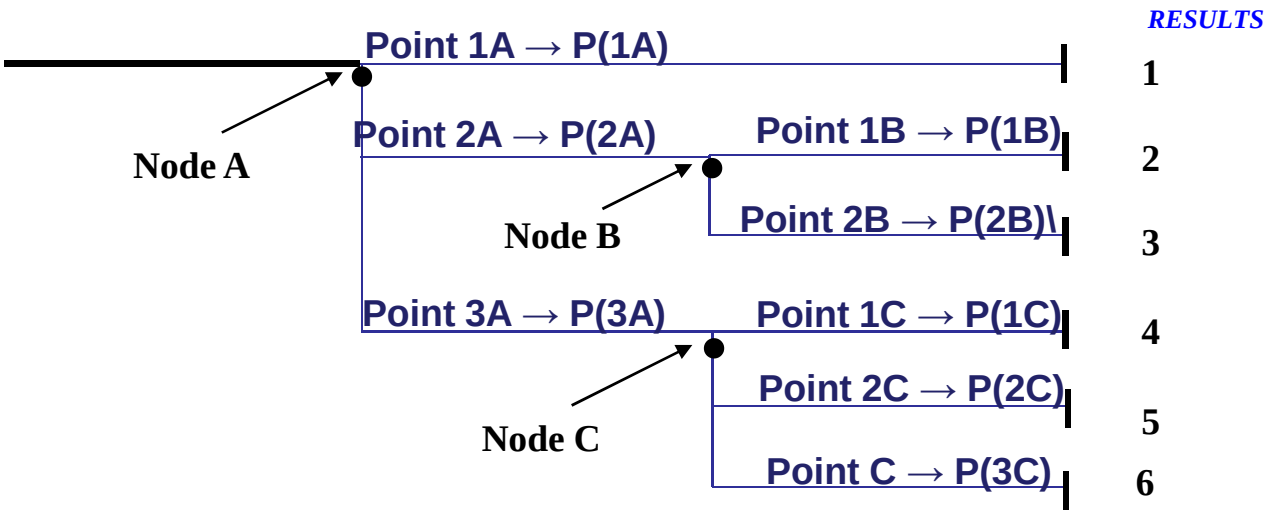
impact energy

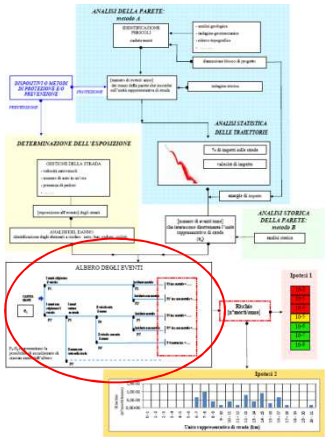
[number of events/year] which directly affect the representative unit of road **($e_j$)**



A specifically developed code was used to develop the Event Tree Analysis a specially **Event Tree Analysis** is a quantitative technique used in risk analysis, suitable for the study of complex and structured systems, such as the collapse or the interactions between a rock block and road infrastructure.

It involves the construction of a graphical model and uses the main probability theorems



"Branch" of the tree → Incidental sequence of events

# *Probability assumed in the Event Tree analysis*

| | ***fatality /year*** |
|---|---|
| ***Probability that a collision between the falling rock blocks and the vehicle leads to a fatal accident***<br>- not all of the vehicle is occupied by passengers;<br>- rock must have sufficient energy to penetrate the body of the vehicle;<br>- the lethality of the accident is due to the loss of vehicle control; | **0.2**<br>**Bunce et al. 1997** |
| ***Probability that a collision between the vehicle and the boulder on the road mleads to a fatal accident***<br>- in most cases, the driver can see the obstacle with a margin of time that is sufficient to allow him to avoid it; | **0,1**<br>**Bunce et al. 1997** |
| ***Probability that the vehicle has an accident due to rough road surfaces***<br>- loss of control: impact with other vehicles, goes off the road, or goes against the rock wall itself;<br>- difficult to estimate, as it depends on the road visibility conditions, lighting, the size of the fallen rocks, the size of the holes on the road, on driver's reaction time, etc ....; | **1.1 10-2**<br>**Road accident statistic, ISTAT** |
| ***Probability that the accident caused by rough road surfaces is mortal*** | **4.9 10-2**<br>**Road accident statistics, ISTAT** |
| ***Probability that the boulder remains on the road track***<br>- function analysis of the trajectories;<br>- percentage of blocks that actually stop on the road compared to all the fallen blocks;<br>- a default value, can be used or calculated adopting an analysis of the trajectories; | **0.5** |
| ***Probability that the boulder damages the road surface and continues***<br>- function of the size of the boulders and their volume | **0.3** |

# *RO.MA. ROckfall risk MAnagement*

**Method A**

**Method B**

DAMAGE ANALYSIS

number of events/year

**Event Tree Analysis**

**ROCKFALL**

The rock blocks strike the vehicle

P1

Fatal accident

P2

P2 Fatal accident =……

Non-fatal accident

P2’

P2’ Non-fatal accident =……

The rock blocks do not strike the vehicle

P1’

The rock blocks fall on to the road

P3

The car hits the rock blocks

P4

Fatal accident

P5

P5Fatal accident=……

Non-fatal accident

P5’

P5’ Non-fatal accident =……

The car does not hit the rock blocks

P4’

P 4 Non accident =…..

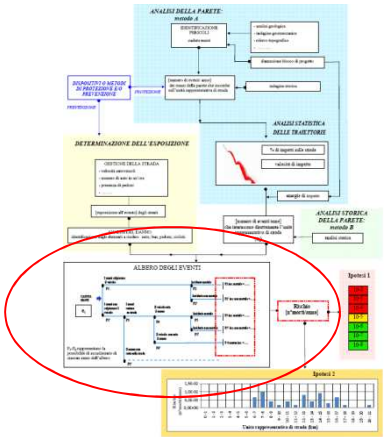
The rock blocks do not stop on the road

P3’

$P_1$-$P_n$ - possibility of occurrence of each branch of the tree

**Risk**
**[n° fatality / year]**

**Risk**
**[n° non fatal accident / year]**



# *RO.MA. ROckfall risk MAnagement*

**Risk** →

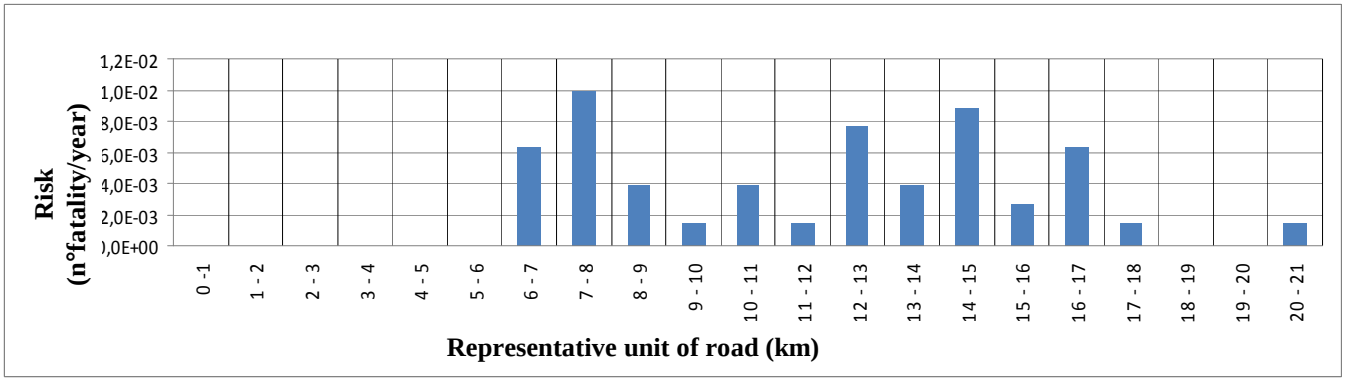
- n° fatality/year
- n° non fatal accident/year

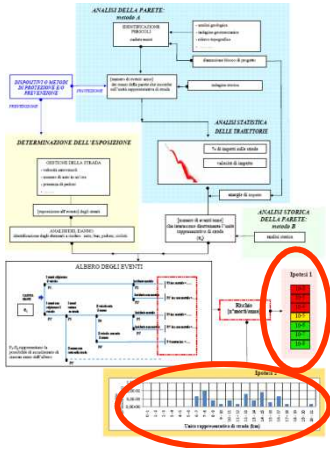
→ ***RISK THRESHOLD***

| |
|---|
| $10^{-2}$ |
| $10^{-3}$ |
| $10^{-4}$ |
| $10^{-5}$ |
| $10^{-6}$ |
| $10^{-7}$ |
| $10^{-8}$ |

?

↓ ***ROAD ZONING***



# *Acceptable risk in technical literature*

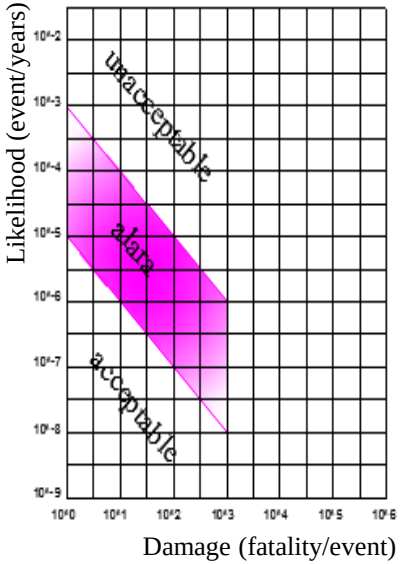
Health and Safety Executive, UK, 1989

Risk (fatality/year)

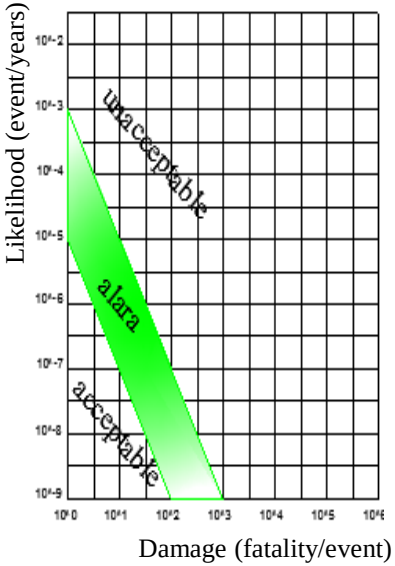
| | |
|---|---|
| $10^{-3}$ | Tolerable risk by an employee during working hours, at workplace |
| $10^{-4}$ | Highest risk for a man (not employee) due to the presence of an industrial nuclear plant |
| $10^{-5}$ | Highest risk for a man (not employee) due to the presence of an industrial non nuclear plant |
| $10^{-6}$ | Acceptable level of risk - natural hazards, no further improvements |

Hong Kong, The Netherlands, The United Kingdom, threshold levels of risk

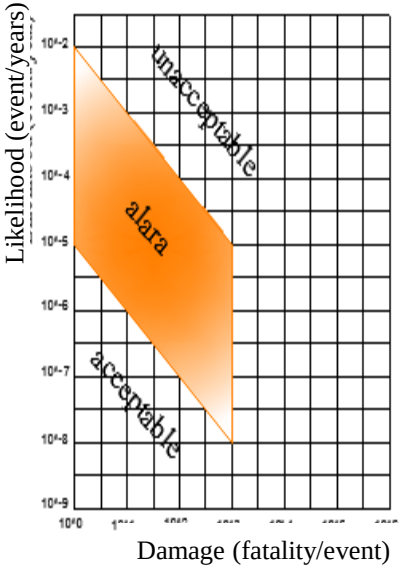
*HONK KONG*




*THE NETHERLANDS*

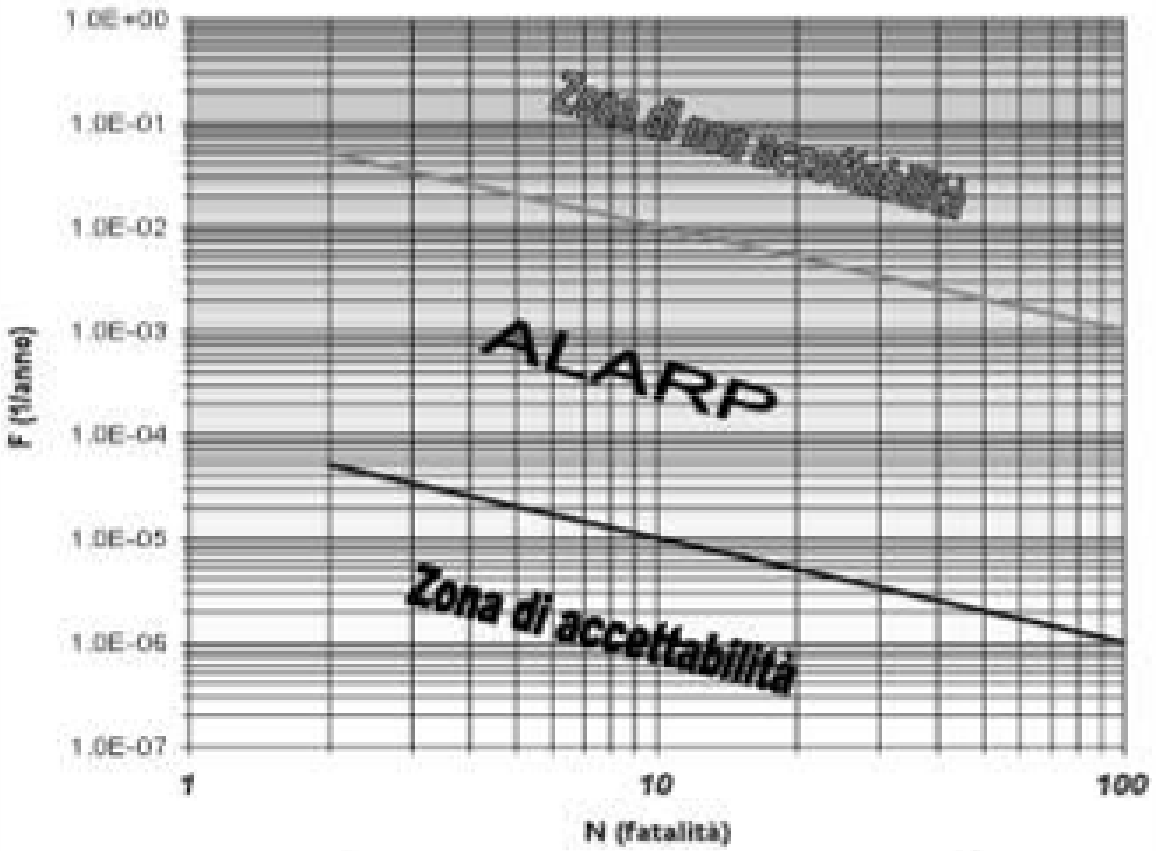



*UNITED KINGDOM*



# *Acceptable risk in technical literature*

ANAS - Guidelines for risk assessment in tunnel: ***IRAM (Italian Risk Analysis Methods)*** (Eu 2004/54/CE)




- Europian White Paper, 2001
- Italian National Road Safety Plan, 2002

$2 \cdot 10^{-4}$ fatality/year

# *Acceptable risk in technical literature*

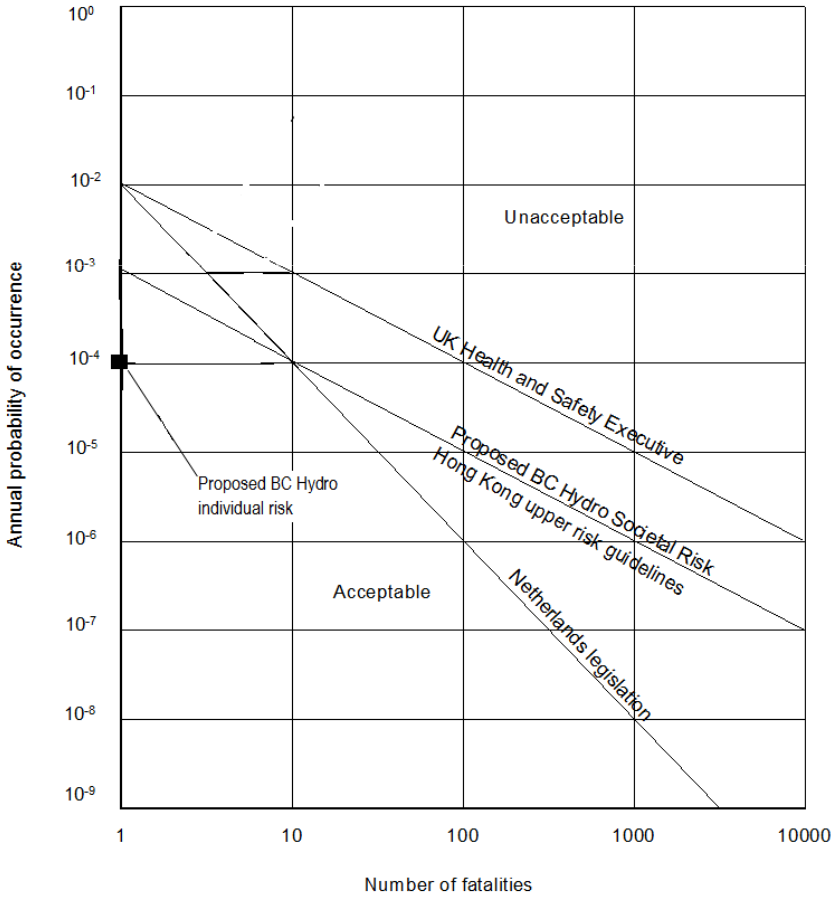
Building area in Iceland in relation to avalanche danger, Jòhannesson and Arnalds, 2001

| Hazard Zone | Lower threshold of risk (fatality/year) | Upper threshold of risk (fatality/year) |
|---|---|---|
| *A* | $3 \cdot 10^{-5}$ | $1 \cdot 10^{-4}$ |
| *B* | $1 \cdot 10^{-4}$ | $3 \cdot 10^{-4}$ |
| *C* | $3 \cdot 10^{-4}$ | - |

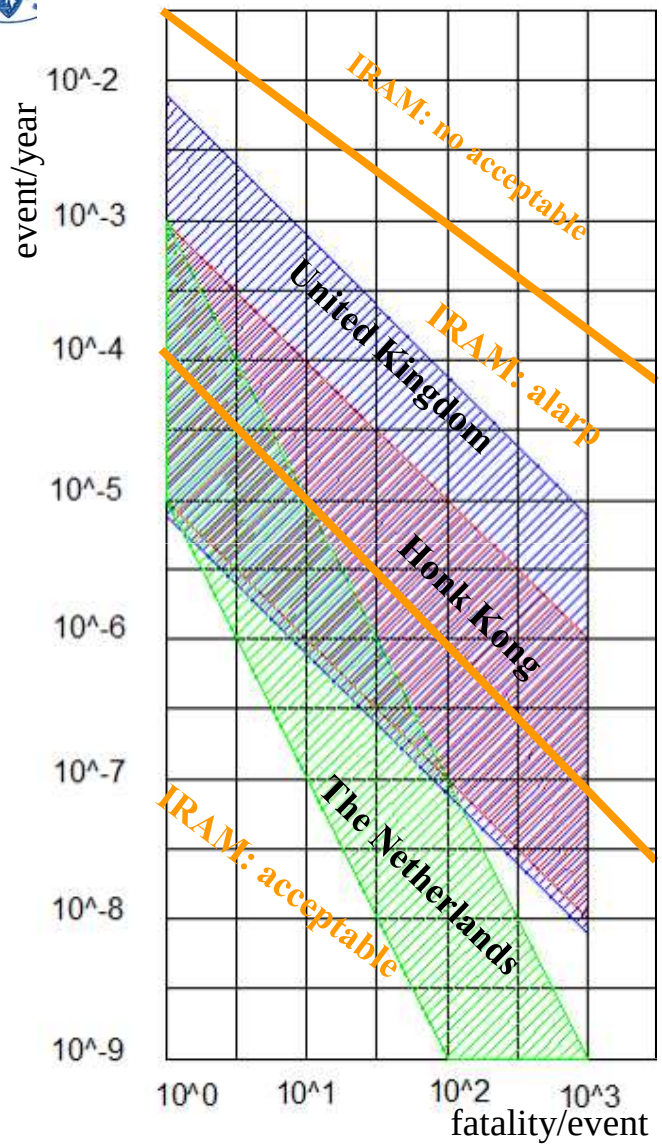
Australian Geomechanics Society, 2000
& Hong Kong, 2005

| | | |
|---|---|---|
| **Building** | Existing | $10^{-4}$ fatality/year |
| | New | $10^{-5}$ fatality/year |

Practical Rock Engineering, Hoek, 2007

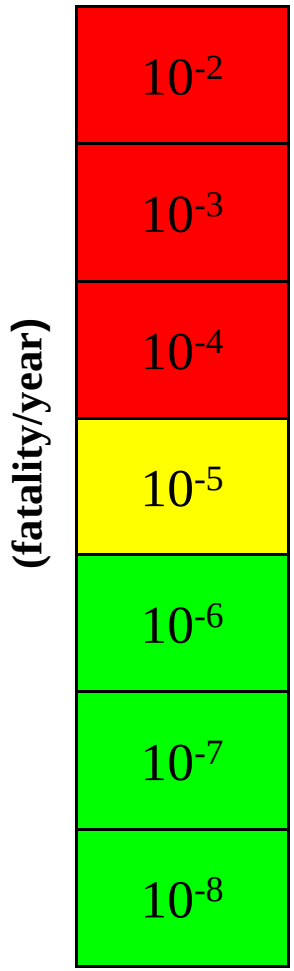


# *Acceptable risk in technical literature: summary*




| Risk (fatality/ year) | |
|---|---|
| **1·10$^{-3}$** | Tolerable risk by an employee during working hours, at workplace<br>*Health and Safety Executive UK, 1989* |
| **3.10$^{-4}$** | Lower threshold of risk area C - Building areas in Iceland<br>*Jòhannesson and Arnalds, 2001* |
| | Upper threshold of risk area B - Building areas in Iceland<br>*Jòhannesson and Arnalds, 2001* |
| **2·10$^{-4}$** | Europian White Paper, 2001 |
| | Italian National Road Safety Plan, 2002 |
| **1·10$^{-4}$** | Highest risk for a man (not employee) due to the presence of an industrial nuclear plant<br>*Health and Safety Executive UK, 1989* |
| | Lower threshold of risk area B - Building areas in Iceland<br>*Jòhannesson e Arnalds, 2001* |
| | Upper threshold of risk area A- Building areas in Iceland<br>*Jòhannesson and Arnalds, 2001* |
| | Existing Building<br>*Australian Geomechanics Society, 2000 & Hong Kong, 2005* |
| **3 10$^{-5}$** | Lower threshold of risk area A - Building areas in Iceland<br>*Jòhannesson and Arnalds, 2001* |
| **1·10$^{-5}$** | Highest risk for a man (not employee) due to the presence of an industrial non nuclear plant<br>*Health and Safety Executive UK, 1989* |
| | New Building<br>*Australian Geomechanics Society, 2000 & Hong Kong, 2005* |
| **1·10$^{-6}$** | Acceptable level of risk - natural hazards, no further improvements<br>*Health and Safety Executive UK, 1989* |

## *Our risk threshold proposal*

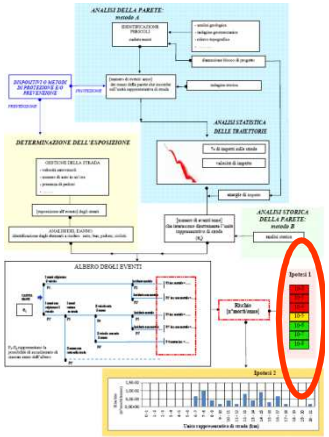



### *Comparison Tool*

- between the calculated risk and the risk that is considered acceptable;
- between the calculated state of the art risk and the risk after building of the device;

It can be used both during risk assessment tand in the design stage;

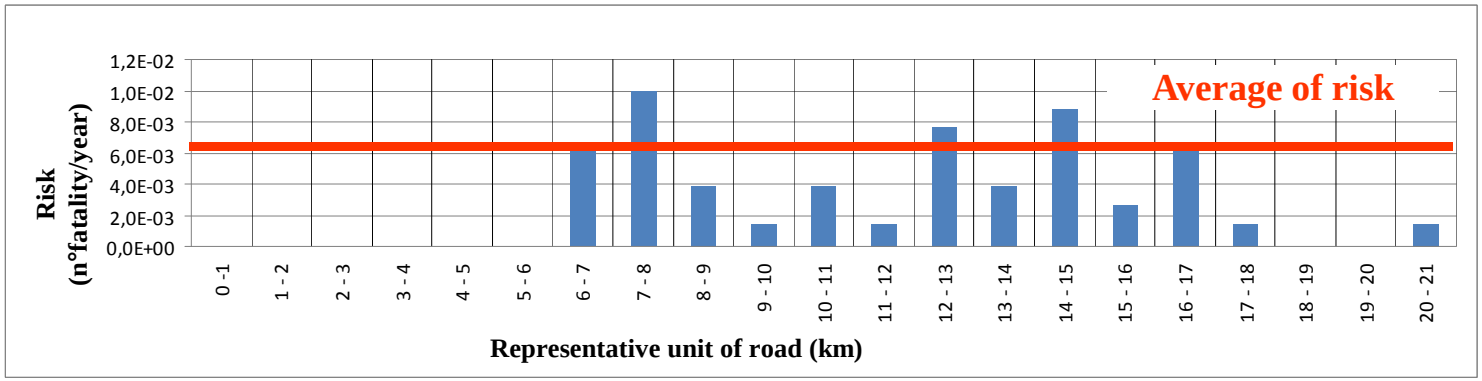
It helps the engineer to quantify the improvements in terms of risk reduction achieved through a correct design

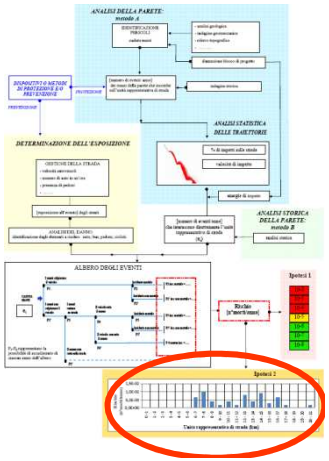


# *RO.MA. ROckfall risk Management: second approach*

Calculate the risk to the examined road and then compare it with the average risk of entire road or an area risk

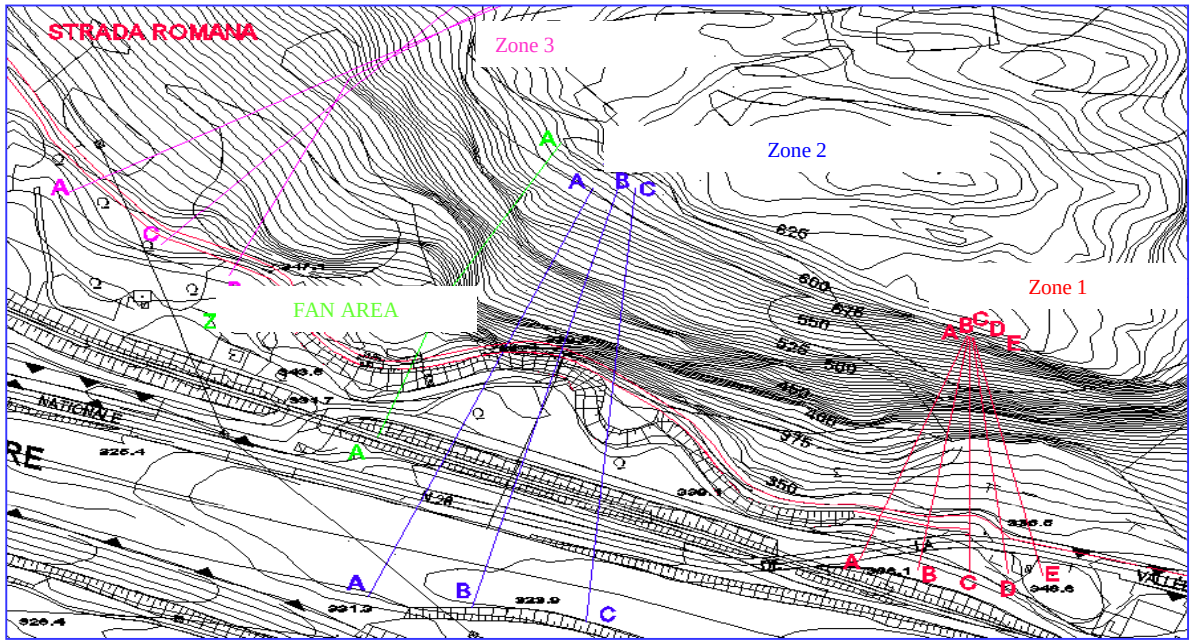
You need to develope:
- a representative database;
- an analysis of the historical data;
- An analysisi for each stretch of the road

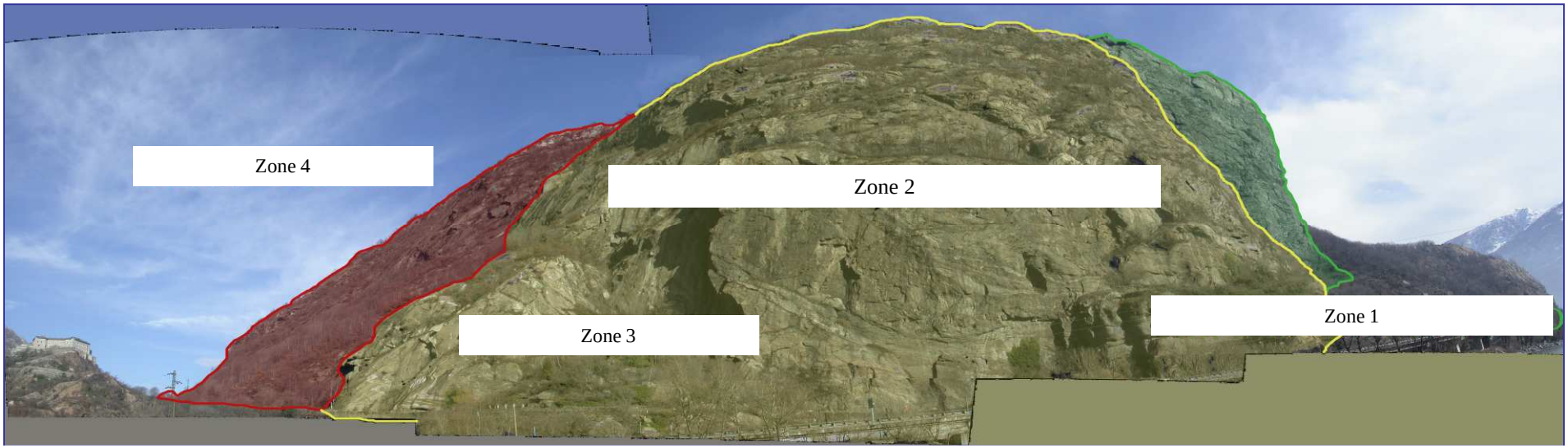


# Example

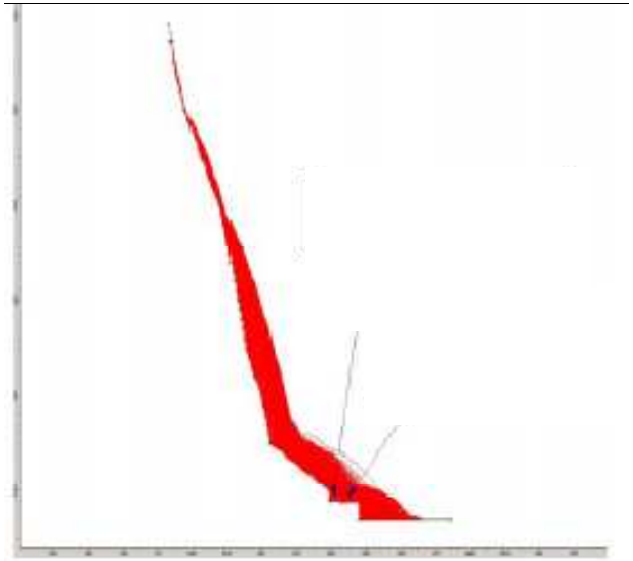
The route of the access road to Bard Fortress subjcted to rockfall phneomena has been divided into homogeneous zones and singularly studied



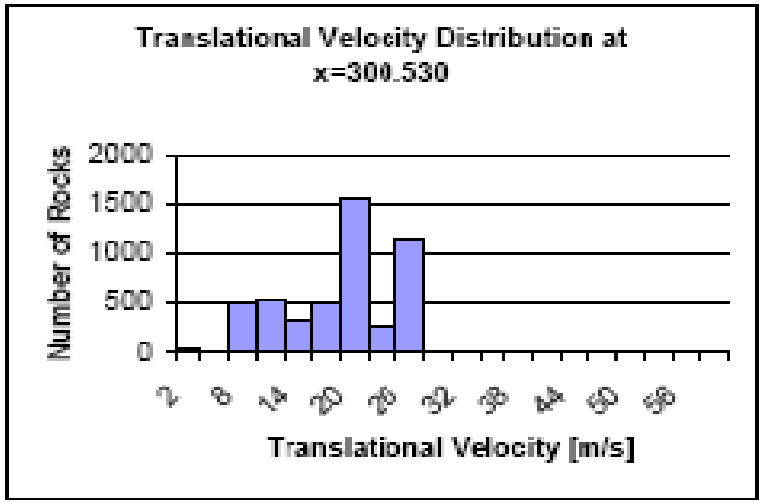



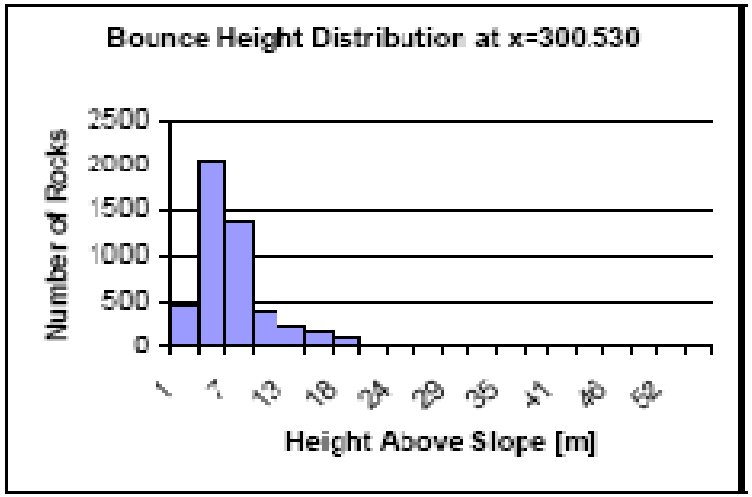
# Example

without mitigation devices



**n° rockfall on the road: 321/10000**

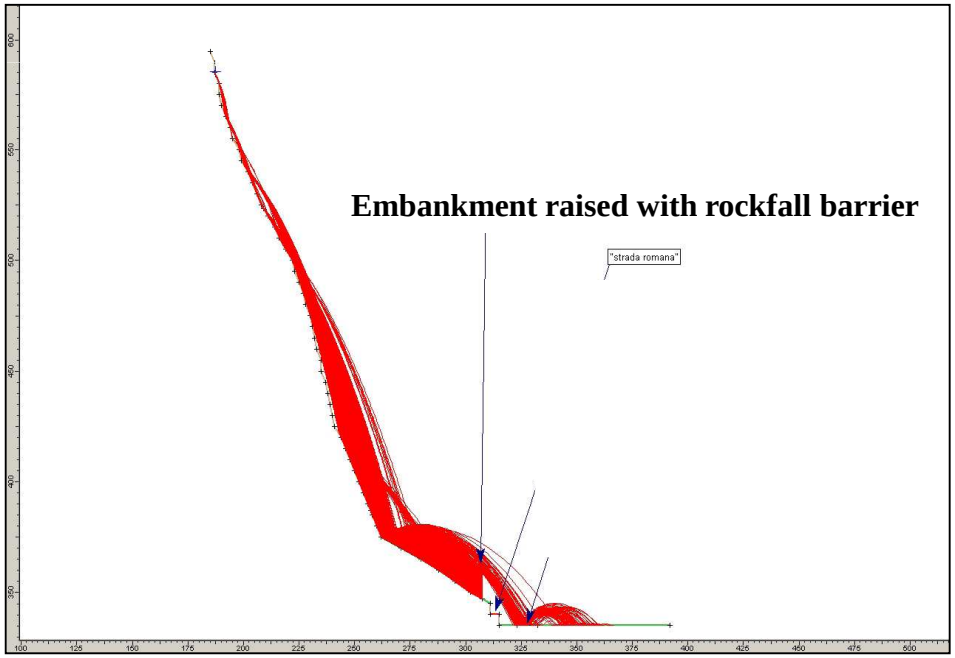


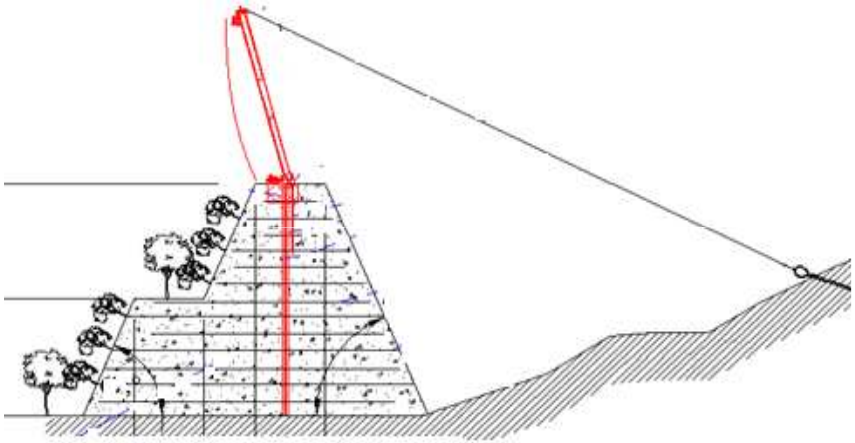
# Example

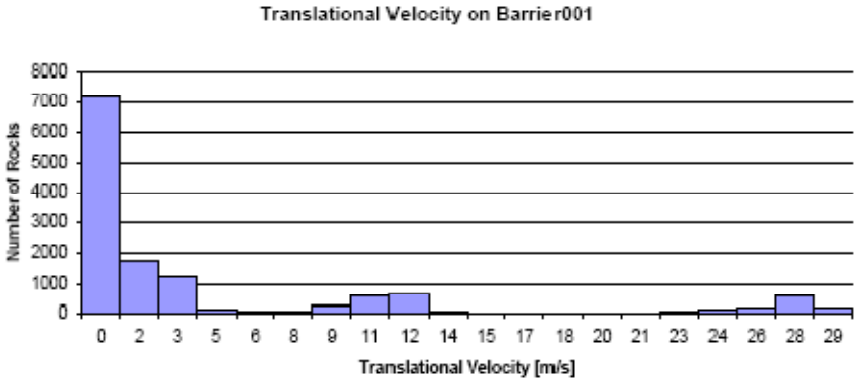
with mitigation devices

**n° rockfall on the road: 1/10000**




**Embankment raised with rockfall barrier**





# Example

| | No device of mitigation<br><br>**Risk (n°fatality/year)** | Device of mitigation<br><br>**Risk (n°fatality/year)** | **Studied mitigation device** |
|---|---|---|---|
| Stretch 1 | $9.47 \cdot 10^{-3}$ | $9.8 \cdot 10^{-7}$ | embankment raised with rockfall barrier |
| Stretch 2 | $9.22 \cdot 10^{-3}$ | $1.01 \cdot 0^{-6}$ | Rockfall barrier |
| Stretch 3 | $9.35 \cdot 10^{-3}$ | $9.92 \cdot 10^{-7}$ | natural or artificial tunnel |
| Stretch 4 | $9.49 \cdot 10^{-3}$ | $9.78 \cdot 10^{-7}$ | net fences |