MACCAFERRI

Zajištění skalních masivů Povrly - Děčín hl.n. km 528,350 - 528,500 a 529,400 - 529

Recommended Rock Slope Mitigations for CH 29 500

Version 02

Document Control Information

Project Name: Zajištění skalních masivů Povrly - Děčín hl.n. km 528,350 - 528,500 a 529,400 - 529,950 - Recommended Rock Slope Mitigations for CH 29 500

Project Reference: Ing. Jakub Šíma Tel.: +420602737553 e-mail: sima@azconsult.cz

Client: AZ Consult, spol. s r.o., Klíšská 12, 400 01 Ústí nad Labem

Maccaferri Office: OM CE – support sw ITALY

VIA Kennedy 10 Zola Predosa (Bologna)

www.maccaferri.com

Rev.	Date	By	Changes
1.0	April 25 13	gg	First release to client
2.0	May 8 13	gg	Design boulder: size reduced – Barrier: reduced, working for SEL

Introduction

The technical solution hereby proposed concerns the Rock Slope Mitigations at CH 29 500 of the project Zajištění skalních masivů Povrly - Děčín hl.n. km 528,350 - 528,500 a 529,400 - 529,950.

The suggested remedial solution consists in a rockfall barrier with a capacity of 1500 kJ and 4.0 m height. The barrier is easy to be installed and transported on the slope. Considering the rockfall trajectories and the needed distance from the railway, the best location of the structure is 10 m above the line track (measured on the horizontal direction, that is 13 – 14 m on the slope).

In attachment at the present report, there are

- Note with the forces acting on the foundation system
- Typical drawings.
- Technical data sheet

Calculation criteria

The main criteria leading the project are the followings:

- Because the intervention is aimed at the protection of a railway, the global safety factor must be height in order to minimize any risks for the traffic.
- In order to minimize the maintenance, the barrier must be oversized, because any maintenance means interruption of the train traffic and probability of damages. In the present case the barrier has been oversized, considering the Service Energy Level (SEL), according to the design standards and the European Technical Approval Guideline 027. The SEL design approach implicates that the energy of impact (design energy) is equals to one third of the nominal capacity of the barrier; this approach reduces the maintenance on the structure and the risk level for the railway.

Calculation procedure

The calculation procedures utilizes amplification coefficients of the energy (equivalent to the force acting) and reduction of the capacity (that is the resistance of the barrier), in agreement with the suggestions of the technical procedure and literature[1]. The coefficients depend upon the quality of the rockfall simulation and of the geomechanical information.

The design capacity of the barrier is defined as:

$E_{BTE} / (\gamma_{EN} * i)$

Where

E_{BTE} = maximum energy capacity of the barrier has been defined with the crash test in agreement with the MEL test of ETAG 27 (European Technical Approval Guideline for rockfall protection kits).

γ_{EN} = reduction coefficient of the capacity of the barrier. It usually is 1.2.

i = corrective coefficient that take into account of the environment of installation of the barrier. It ranges between 1.0 and 1.2.

The design energy of impact of the boulder is defined as:

Ed = 1/2 * Md * Vd ^2

Where

$Vd = Vt * \gamma tt * \gamma tr$ = velocity of design

$Md = St * \gamma tg * W * \gamma tw$ = mass of design

Vt = Velocity calculated with the rockfall simulation at the 98% percentile

St, W = Size and weight of the boulder of design

and the coefficients of amplification are the following:

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[1] Design Standard UNI 11211-4: 2012

see also Peila D., Oggeri C., Baratono P. – Quaderni GEAM 25 – Turin (in Italian)

γ_{tt} = it considers the quality of Topographic survey, that ranges between 1.01 (good topographic survey) and 1.07 (bad quality survey)

γ_{tg} = it considers the quality of Geomechanical survey for the size, that ranges between 1.01 (good quality of sizing) and 1.07 (no survey available)

γ_{tw} = it considers the quality of Geomechanical survey for the density, that ranges between 1.0 and 1.05 (usually 1.0 is taken)

γ_{tr} = it considers the quality of rock fall simulation , that ranges between 1.02 (simulation performed in back analysis) and 1.07 (simulation base upon bibliographic coefficients)

The energy of the barrier is proofed if

$(Ed - E) \leq 0$

The height of the barrier is proofed if

$(Hd - H) \leq 0$

Where Hd is the design trajectory height, with

$Hd = Ht * \gamma tt * \gamma tr$ + Boulder radius =

$Ht = \cos(\alpha - \beta) * Hv$ = Height of the trajectories at the 98% percentile, measured on barrier plane

Hv = height of the trajectories at the 98% percentile, measured on the vertical

α, β = inclination of the slope, tolerance of inclination of the barrier

$\gamma tt * \gamma tr$ = amplification coefficients, as in the previous formulas

and

$H = Hb - Fb$ = height of the barrier, with

Hb = nominal height of the barrier

Fb = span of the upper free border of the barrier that cannot be impacted by the center of mass of the boulder.

It is needed also that the elongation of the barrier increased by a safety coefficent is shorter than the distance between the barrier and the infrastructure to be protected:

$(D - Di) \leq 0$

Where

D = Db * γ_{DB}

b = Maximum deformation measured on the crash test MEL of ETAG 27

γ_{DB} = coefficient of amplification e of the elongation, equals to 1.3.

Below there is the development of the calculation:

Calculation output

Rockfall section n.		3	
Rockfall barrier n.		1	
Barrier model		**RB 1500**	
Nominal maximum energy level of the barrier	**MEL**	1500	[kJ]
Maximum energy level of the barrier		1637	[kJ]
Data analysis			
Simulation developped with		3000	trajectories
Confidence limit: statistical approach on the		98%	of the population
Inclination of the data collector on the rockfall simulation	[ε_datac]	data collector vertical	
Average inclination of the slope in the barrier point	[α]	45.00	[°]
Tollerance for the barrier inclination from the post inclination	[β]	0.00	[°]
Trajectory height on the vertical for the 98% of the cases	[Hv]	0.99	[m]
Trajectory height on the barrier plane (HP: impact perpendicular to the barrier plane)	[Ht]	0.70	[m]
Minimum distance between barrier and infrastructure	[Di]	10.00	[m]
Velocity (translational) - confidence limit 98%	[Vt]	21.07	[m/s]
Block size	[Volb]	0.22	[m3]
Block shape	[shape]	cube	
Average diameter of the block	[DN]	0.60	
Unit weight of the rock	[γ]	2900	[kg/m3]

Partial safery coefficient			
Quality of the Topographic survey	[γDp]	1.07	
Quality of the Geomechanical survey - size	[γVolF1]	1.07	
Quality of the Geomechanical survey - unit weight	[γγ]	1.00	
Quality of the rockfall simulation	[γTr]	1.08	

Design trajectory			
Design velocity [Vt * γTr * γDp]	[Vd]	24.35	[m/s]
Design mass [Volb *γVolF1 * γ * γγ]	[Md]	670.25	[kg]
Design height [Ht * gTr * γDp + DN/2]	[Hd]	1.11	[m]

Design Energy [0.5 * Md * Vd ^2]	[Ed]	198.68	[kJ]

MACCAFERRI rockfall barrier features			
Maximum Energy Level according to ETAG 27	[MEL]	1637.00	[kJ]
Serviceability Energy Level according to ETAG 27	[SEL]	525.00	[kJ]
Maximum dynamic elongation of the barrier at the MEL test	[Db]	5.80	[m]
Standard height of the barrier: between 4 m and 5 m			
Nominal height of the CERTIFIED barrier	[Hb]	4.0	[m]

Design Method			
Design procedure aimed to (MEL or SEL)	SEL		
Service Energy Level - using energy	$[E_{BARRIERA}]$	525.00	[kJ]
Amplification factor which considers the risk of places having:			
(2)_high economical value, but can be easily repaired	[i]	1.05	
Number of span of the barrier	more than 3 spans		
Safety coefficient for reduction of the barrier energy	$[\gamma_E]$	1.0	
Safety coefficient for the deformation	$[\gamma_{DB}]$	1.0	
Upper free border for the barrier height (MIN 0.5 m)	[Fmin]	1.0	[m]

Design Performance of the Barrier			
Design Energy [Ed *i]	[Esd]	208.61	[kJ]
Design Deformation [Db * γ_{DB}]	[Dd]	5.8	[m]
Design Height [Hd + Fmin]	[Htot]	2.1	[m]

Barrier Proof			
Energy proof [(Esd - Ebarriera/ γE) ≤ 0]		-316.4	Fullfilled
Elongation proof [(Dd - Di) ≤ 0]		-4.2	Fullfilled
Height proof [(Htot - Hb) ≤ 0]		-1.9	Fullfilled
SAFETY COEFFICIENT OF THE DESIGNED BARRIER:	**SF =**	**1.49**	**design at SEL**

RESIDUAL HEIGHT CHECK: by analyzing the cumulative curve of the heights on the rockfall simulation			
Residual height of the barrier after the impact	[Hres]	3.3	[m]
Residual height proof at the 98% [Hd - Hres) ≤ 0]		-2.2	Fullfilled at 98%
% of blocks can be stopped by the impacted barrier (see cumulative distribution of the heights on the rockfall simulation)	[H%]	98%	(from the simulation)

Rockfall analysis input data

Units: Metric
Friction angle: Use friction fngle specified in material editor
Minimum Velocity=0.1
Angular Velocity of the rocks CONSIDERED
Standard Deviations USED when generating slope vertices
Random-number generation: Random

Slope

Segment 1, Material: Clean hard bedrock [default]
Start Point: X mean=50.7573 std dev=0.25 Y mean=65.153 std dev=0.25
End Point: X mean=54.6024 std dev=0.25 Y mean=64.3223 std dev=0.25

Segment 2, Material: Clean hard bedrock [default]
Start Point: X mean=54.6024 std dev=0.25 Y mean=64.3223 std dev=0.25
End Point: X mean=55.4925 std dev=0.25 Y mean=61.9745 std dev=0.25

Segment 3, Material: Clean hard bedrock [default]
Start Point: X mean=55.4925 std dev=0.25 Y mean=61.9745 std dev=0.25
End Point: X mean=58.4863 std dev=0.25 Y mean=61.9745 std dev=0.25

Segment 4, Material: Clean hard bedrock [default]
Start Point: X mean=58.4863 std dev=0.25 Y mean=61.9745 std dev=0.25
End Point: X mean=59.4573 std dev=0.25 Y mean=59.3838 std dev=0.25

Segment 5, Material: Clean hard bedrock [default]
Start Point: X mean=59.4573 std dev=0.25 Y mean=59.3838 std dev=0.25
End Point: X mean=60.8329 std dev=0.25 Y mean=57.5217 std dev=0.25

Segment 6, Material: Clean hard bedrock [default]
Start Point: X mean=60.8329 std dev=0.25 Y mean=57.5217 std dev=0.25
End Point: X mean=63.058 std dev=0.25 Y mean=56.7931 std dev=0.25

Segment 7, Material: Clean hard bedrock [default]
Start Point: X mean=63.058 std dev=0.25 Y mean=56.7931 std dev=0.25
End Point: X mean=65.1618 std dev=0.25 Y mean=54.7691 std dev=0.25

Segment 8, Material: Clean hard bedrock [default]
Start Point: X mean=65.1618 std dev=0.25 Y mean=54.7691 std dev=0.25
End Point: X mean=68.4091 std dev=0.25 Y mean=53.1977 std dev=0.25

Segment 9, Material: Clean hard bedrock [default]
Start Point: X mean=68.4091 std dev=0.25 Y mean=53.1977 std dev=0.25
End Point: X mean=71.3518 std dev=0.25 Y mean=51.7737 std dev=0.25

Segment 10, Material: Clean hard bedrock [default]
Start Point: X mean=71.3518 std dev=0.25 Y mean=51.7737 std dev=0.25
End Point: X mean=70.8258 std dev=0.25 Y mean=49.7497 std dev=0.25

Segment 11, Material: Clean hard bedrock [default]
Start Point: X mean=70.8258 std dev=0.25 Y mean=49.7497 std dev=0.25
End Point: X mean=73.8197 std dev=0.25 Y mean=48.0496 std dev=0.25

Segment 12, Material: Clean hard bedrock [default]
Start Point: X mean=73.8197 std dev=0.25 Y mean=48.0496 std dev=0.25
End Point: X mean=77.1776 std dev=0.25 Y mean=45.2565 std dev=0.25

Segment 13, Material: Clean hard bedrock [default]
Start Point: X mean=77.1776 std dev=0.25 Y mean=45.2565 std dev=0.25
End Point: X mean=78.7959 std dev=0.25 Y mean=43.3135 std dev=0.25

Segment 14, Material: Clean hard bedrock [default]
Start Point: X mean=78.7959 std dev=0.25 Y mean=43.3135 std dev=0.25
End Point: X mean=84.9859 std dev=0.25 Y mean=41.8157 std dev=0.25

Segment 15, Material: Clean hard bedrock [default]
Start Point: X mean=84.9859 std dev=0.25 Y mean=41.8157 std dev=0.25
End Point: X mean=87.6471 std dev=0.25 Y mean=38.336 std dev=0.25

Segment 16, Material: Clean hard bedrock [default]
Start Point: X mean=87.6471 std dev=0.25 Y mean=38.336 std dev=0.25
End Point: X mean=89.4631 std dev=0.25 Y mean=35.9615 std dev=0.25

Segment 17, Material: Clean hard bedrock [default]
Start Point: X mean=89.4631 std dev=0.25 Y mean=35.9615 std dev=0.25
End Point: X mean=92.1063 std dev=0.25 Y mean=32.5054 std dev=0.25

Segment 18, Material: Clean hard bedrock [default]
Start Point: X mean=92.1063 std dev=0.25 Y mean=32.5054 std dev=0.25

End Point: X mean=97.7704 std dev=0.25 Y mean=28.2956 std dev=0.25

Segment 19, Material: Clean hard bedrock [default]
Start Point: X mean=97.7704 std dev=0.25 Y mean=28.2956 std dev=0.25
End Point: X mean=99.5876 std dev=0.25 Y mean=25.153 std dev=0.25

Segment 20, Material: Bedrock outcrops [default]
Start Point: X mean=99.5876 std dev=0.25 Y mean=25.153 std dev=0.25
End Point: X mean=106.169 std dev=0.25 Y mean=19.7754 std dev=0.25

Segment 21, Material: Bedrock outcrops [default]
Start Point: X mean=106.169 std dev=0.25 Y mean=19.7754 std dev=0.25
End Point: X mean=112.639 std dev=0.25 Y mean=14.4886 std dev=0.25

Segment 22, Material: Bedrock outcrops [default]
Start Point: X mean=112.639 std dev=0.25 Y mean=14.4886 std dev=0.25
End Point: X mean=119.567 std dev=0.25 Y mean=8.82667 std dev=0.25

Segment 23, Material: Bedrock outcrops [default]
Start Point: X mean=119.567 std dev=0.25 Y mean=8.82667 std dev=0.25
End Point: X mean=126.953 std dev=0.25 Y mean=2.79169 std dev=0.25

Segment 24, Material: Bedrock outcrops [default]
Start Point: X mean=126.953 std dev=0.25 Y mean=2.79169 std dev=0.25
End Point: X mean=130.522 std dev=0.25 Y mean=-0.125114 std dev=0.25

Segment 25, Material: Bedrock outcrops [default]
Start Point: X mean=130.522 std dev=0.25 Y mean=-0.125114 std dev=0.25
End Point: X mean=131.286 std dev=0.25 Y mean=-0.880549 std dev=0.25

Segment 26, Material: Bedrock outcrops [default]
Start Point: X mean=131.286 std dev=0.25 Y mean=-0.880549 std dev=0.25
End Point: X mean=132.044 std dev=0.25 Y mean=-1.10035 std dev=0.25

Segment 27, Material: wall
Start Point: X mean=132.044 std dev=0.25 Y mean=-1.10035 std dev=0.25
End Point: X mean=132.129 std dev=0.25 Y mean=-0.508507 std dev=0.25

Segment 28, Material: Bedrock outcrops [default]
Start Point: X mean=132.129 std dev=0.25 Y mean=-0.508507 std dev=0.25
End Point: X mean=133.114 std dev=0.25 Y mean=-0.501073 std dev=0.25

Segment 29, Material: Bedrock outcrops [default]
Start Point: X mean=133.114 std dev=0.25 Y mean=-0.501073 std dev=0.25
End Point: X mean=133.213 std dev=0.25 Y mean=-2.42942 std dev=0.25

Segment 30, Material: Bedrock outcrops [default]
Start Point: X mean=133.213 std dev=0.25 Y mean=-2.42942 std dev=0.25
End Point: X mean=136.288 std dev=0.25 Y mean=-2.4247 std dev=0.25

Materials

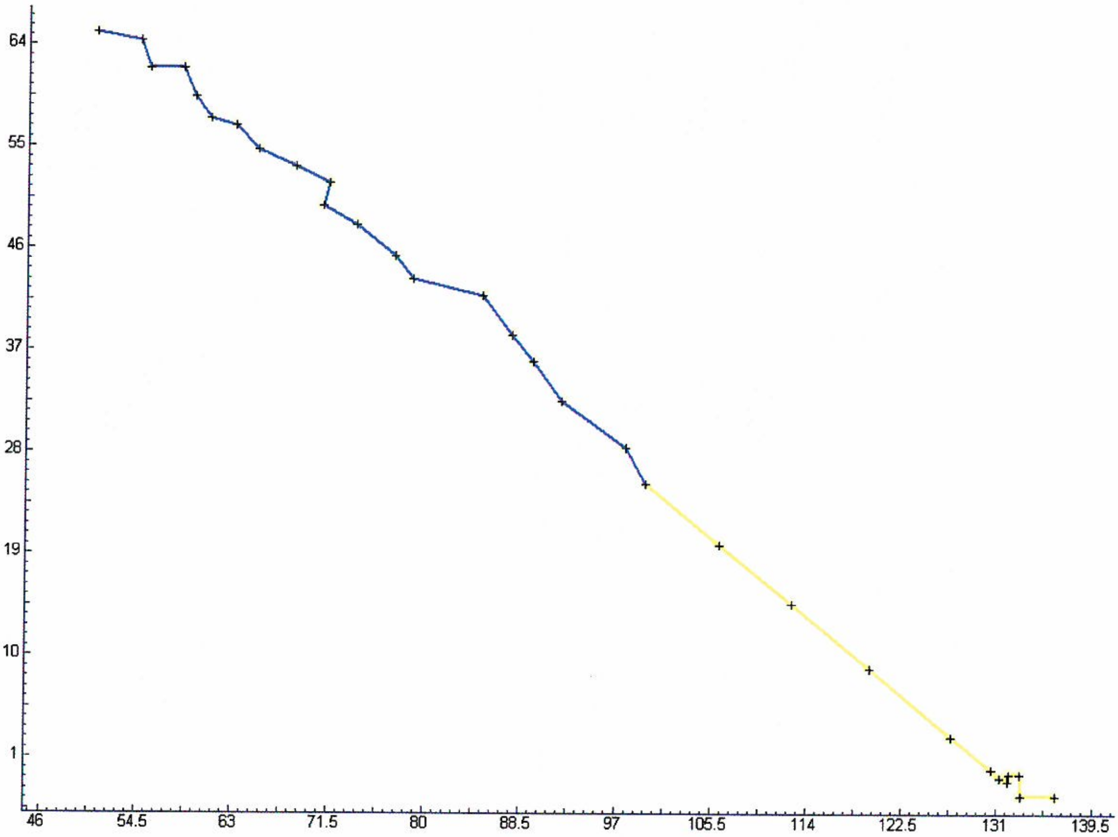
Material name: Clean hard bedrock [default]
Coefficient of Normal Restitution (RN): mean=0.45 std dev=0.04
Coefficient of Tangential Restitution (RT): mean=0.88 std dev=0.04
Friction Angle: mean=27 std dev=3
Roughness: std dev=0

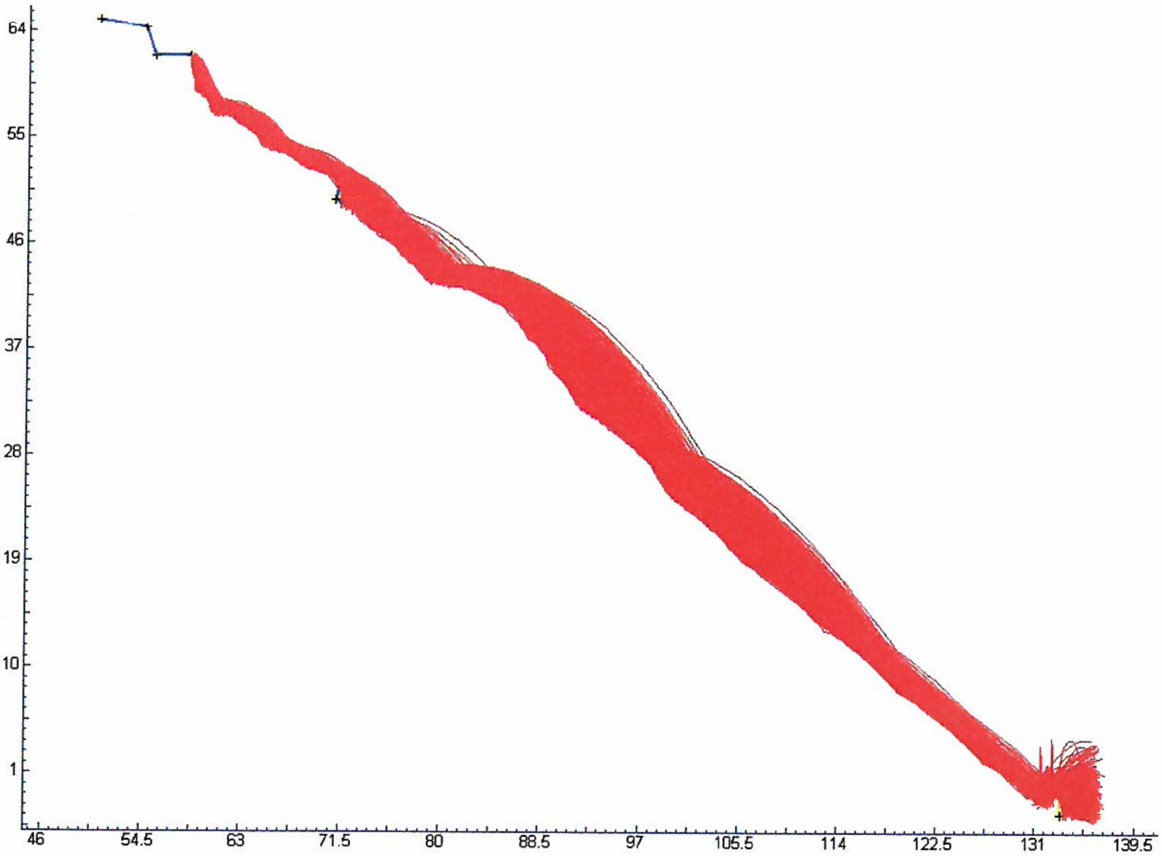
Material name: Bedrock outcrops [default]
Coefficient of Normal Restitution (RN): mean=0.35 std dev=0.04
Coefficient of Tangential Restitution (RT): mean=0.85 std dev=0.04
Friction Angle: mean=29 std dev=3
Roughness: std dev=0

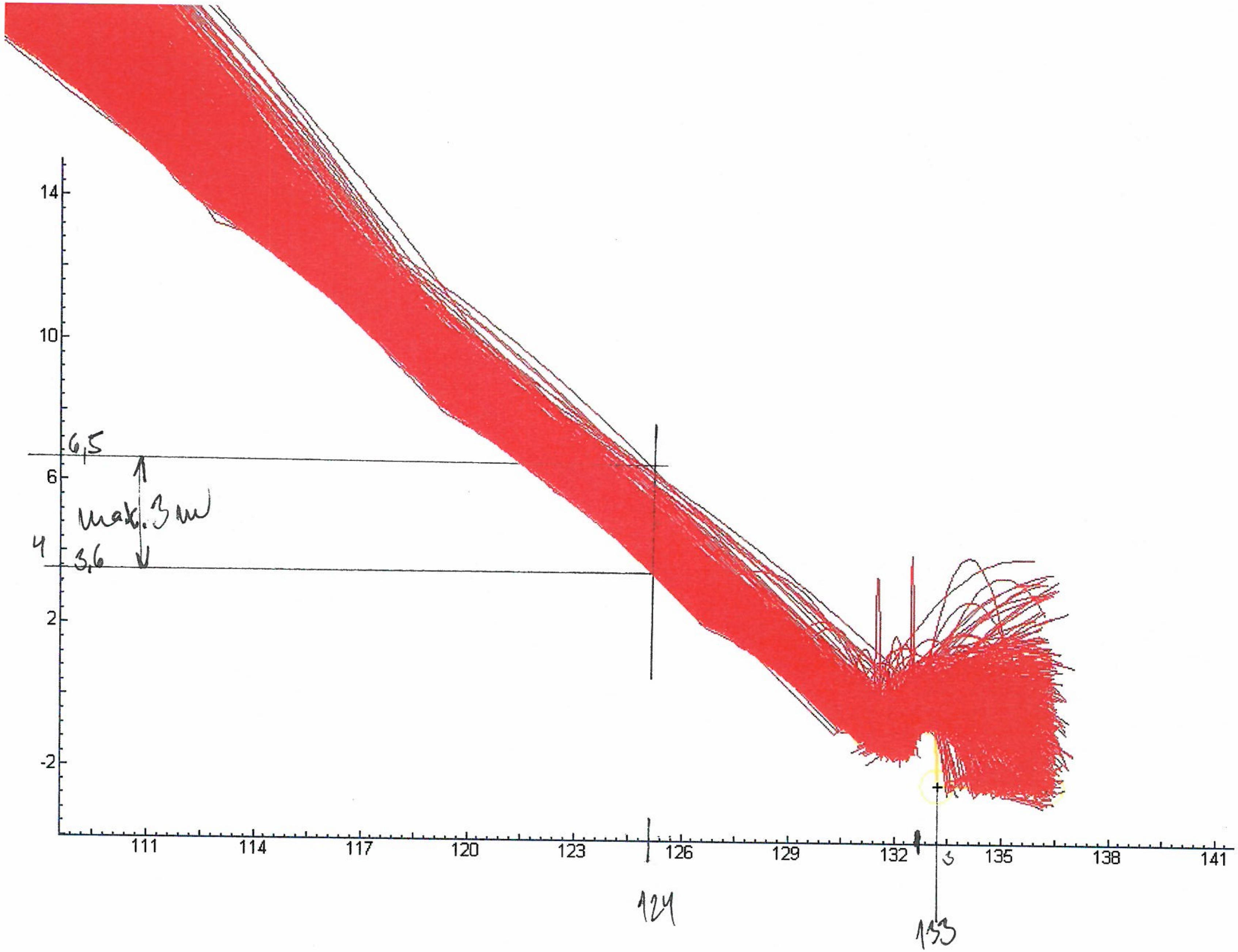
Material name: wall
Coefficient of Normal Restitution (RN): mean=0 std dev=0
Coefficient of Tangential Restitution (RT): mean=0 std dev=0
Friction Angle: mean=0 std dev=0
Roughness: std dev=0

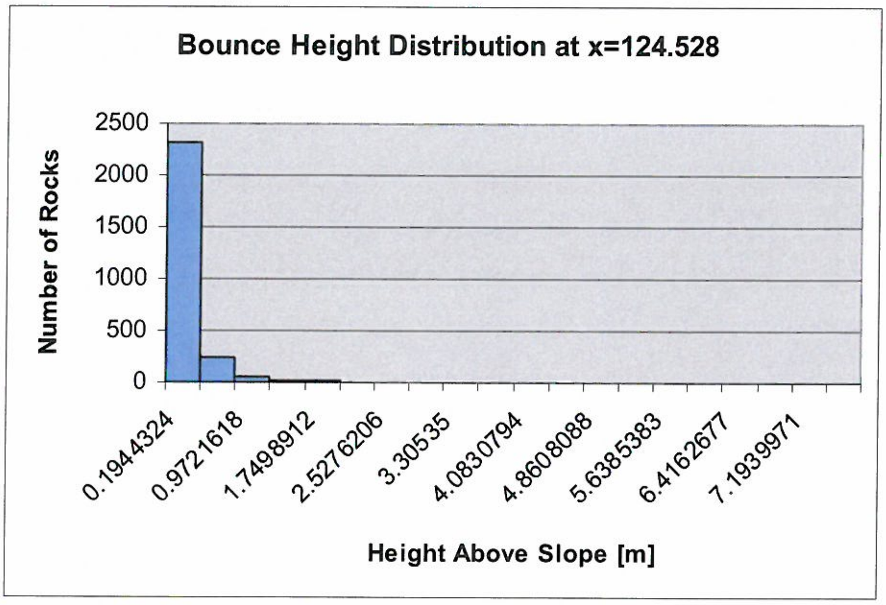
Location (Vertex 1): 58.4863, 61.9745
Location (Vertex 2): 59.4573, 59.3838

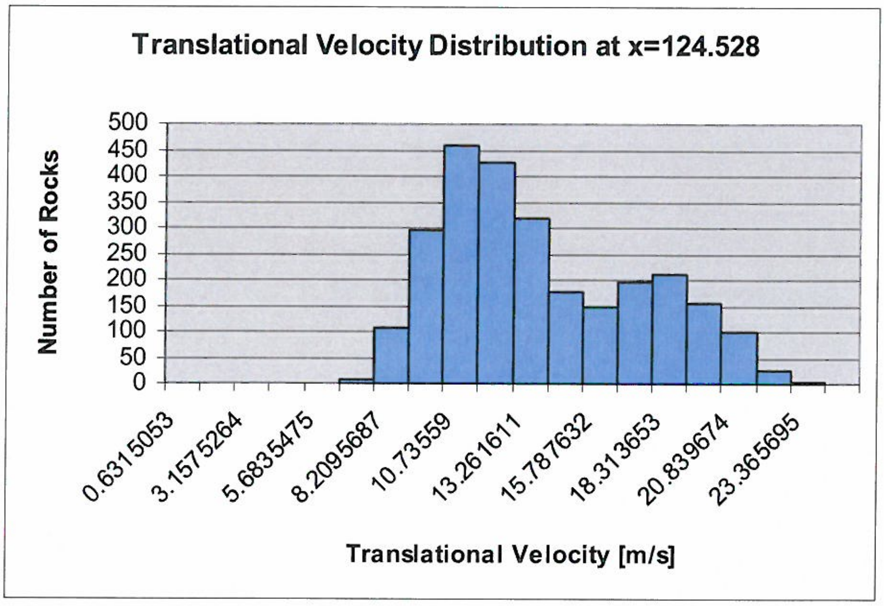
Rockfall analysis output graphics


64
55
46
37
28
19
10
1
46
54.5
63
71.5
80
88.5
97
105.5
114
122.5
131
139.5


64
55
46
37
28
19
10
1
46
54.5
63
71.5
80
88.5
97
105.5
114
122.5
131
139.5


14
10
6
4
2
-2
111
114
117
120
123
126
129
132
135
138
141
6,5
max. 3m
3,6
124
133


Bounce Height Distribution at x=124.528
Number of Rocks
2500
2000
1500
1000
500
0
0.1944324
0.9721618
1.7498912
2.5276206
3.30535
4.0830794
4.8608088
5.6385383
6.4162677
7.1939971
Height Above Slope [m]


Translational Velocity Distribution at x=124.528
Number of Rocks
500
450
400
350
300
250
200
150
100
50
0
0.6315053
3.1575264
5.6835475
8.2095687
10.73559
13.261611
15.787632
18.313653
20.839674
23.365695
Translational Velocity [m/s]

MACCAFERRI

TECHNICAL DATA SHEET

Rev. 01, Date 05.02.2013

MAC.RO. SYSTEM - RB 1500 Plus - 1500 kJ

HIGH RESISTANCE ROCKFALL BARRIER

The RB 1500 Plus rockfall barrier is capable of withstanding the impact of a rock block with energy levels in excess of 1500 kJ, made with components provided with particular coatings able to increase the corrosion resistance when the kit is installed in particularly aggressive (marine, industrial) environments. The barriers "Plus" type are supplied with steel cables coated in class A (EN 10264-2). The barriers "Plus" type are furthermore provided with hot-dip galvanized anchor bars and shackles according to EN ISO 1461, U-bolt wire rope grips according to ASTM A153 and fasteners (bolts and nuts) according to EN ISO 10684.

Standards and Reference Guidelines:
ETAG 027 "Guideline for European Technical Approval of Falling Rock Protection Kits";
SPECIAL SPECIFICATION ANAS "Technical Group on Road Safety" - April 2010.
Standard on materials:
EN 10219 "Cold formed welded structural hollow sections of non-alloy and fine grain steels";
EN 10025-2 "Hot rolled products of structural steels - Part 2: Technical delivery conditions for non-alloy structural steels";
EN ISO 1461 "Hot dip galvanized coatings on fabricated iron and steel articles - Specifications and test";
EN 12385 "Steel wire ropes - Safety;
EN 10264-2 "Steel wire and wire products - Steel wire for ropes - Part 2:cold drawn non alloy steel wire for ropes for general applications";
EN 10244-2 "Steel wire and wire products - Non ferrous metallic coatings on steel wire - Zinc or zinc-alloy coatings".

System technology
The retaining mesh panel is placed on the downslope side of the barrier. Posts acts independently of the net. If a post is hit by falling block and damaged, the adjacent posts take the additional forces, ensuring that the catching performance of the system is not compromised.
The retaining layer is made by steel rings panels, and it is continuous. During an impact, the system ensures that the energy of the falling rock is dissipated, and the rock is prevented from moving any further.
The energy dissipating devices absorb the applied energy by deformation and not by friction, thereby guaranteeing a better and longer lasting performance.
No downslope bracing cables required.
The rockfall barrier meets quality certification standard EN ISO 9001, at each step of design, manufacturing and marketing.

Main barrier features
The barrier can be installed on any rock and soil type and profile. The barrier layout makes it ideal for use on rugged slope.
Due to the system geometry and layout, the bracing cables require smaller pull out resistance, therefore shorter anchor lengths are needed at the base of the cables.
Posts plinths have only a ground-smoothing purpose. The applied forces are transferred to the ground through steel bars or micropiles.
The system is easy to install, even under severe environmental conditions; the installation can be accomplished in a short time.
The system requires minimal maintenance.
The main interception structure consists of steel rings panels.

Tab. 1 - TYPICAL SIZE OF RB 1500 BARRIER

HEIGHT (m)	POST-TO-POST DISTANCE (m)
4.0 - 5.0	8 - 12

Design
The minimum rockfall barrier length is 30 m. The optimum barrier length is between 30 m and 70 m.
Foundation design is dependent on the forces acting at the base, and on the soil type. If the slope geometry produces an offset in the barrier alignment, causing an upslope angle measuring less than 180° (e.g. 160°), a downslope anchor is required. Foundation design depends on the forces acting at the base of the posts and on the cables, and the soil type.

When ordering, declare the type of foundation (for rocky soil or loose soil).

Carried out tests and main data
Dynamic impact test on a full scale barrier sample of 3 spans, 10 m post-to-post distance, and 4 m height. The test program was drawn up and carried out following the instructions provided in the document "ETAG 027 – Guideline for European Technical Approval of Falling Rock Protection Kits".

MEL (Maximum Energy Level) test results:
Energy: 1637 kJ
Barrier Nominal Height: 4.0 m
Maximum Barrier Elongation: 5.80 m
Barrier Residual Height > 61% of the nominal height - Category A of ETAG 027

ETA n. 12/0396

CE
1301 - CPD - 0835

WARNING: Install the product in accordance with National Security Requirements! If the job is done with suspension or security ropes, personal protective equipment against fall risk must be connected with anchor points in agreement with EN 795.

Officine Maccaferri S.p.A.
Via Kennedy, 10 - 40069 Zola Predosa (BO) - Italy
Tel. (+39) 051-6436000 - Fax (+39) 051-6436201
E-mail: comes@maccaferri.com - Web site: www.officinemaccaferri.com