Guideline for the approval of rockfall protection kits

Author: Werner Gerber

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Abstracts

Keywords:
approval, rockfall, protective nets, guideline, natural hazard, rockfall protection kit

For protective nets against rockfall to be compared objectively, they must be subjected to the crash test. The present guideline specifies the procedure for the approval and describes the test criteria, the testing methods and requirements which must be met by the nets. It is an aid to clients, authors of projects, suppliers and producers of protective nets, building contractors and authorities.

Stichwörter:
Typenprüfung, Steinschlag, Schutznetze, Richtlinie, Naturgefahr


Mots-clés:
Homologation, chute de pierres, filets de protection, directive, danger naturel

Pour que les filets de protection contre les chutes de pierres puissent être comparés de manière objective, il faut qu’ils soient soumis au crash test. La présente directive règle le déroulement de l’homologation et décrit les critères et les méthodes d’examen ainsi que les exigences auxquelles doivent satisfaire les filets. Elle constitue une aide pour les maîtres d’œuvre, les auteurs de projets, les fournisseurs et les fabricants de filets de protection, les entrepreneurs et les autorités.

Parole chiave:
Procedura di omologazione, caduta di sassi, reti di protezione paramassi, direttiva, pericolo naturale

Per dare una valutazione oggettiva delle reti di protezione paramassi è necessario collaudarle. La presente direttiva regola la procedura di omologazione e descrive i criteri e i metodi di valutazione, nonché le esigenze che tali reti devono soddisfare. La direttiva è destinata ai committenti, ai progettisti, ai fornitori o ai fabbricanti delle reti, alle imprese edilizie e alle autorità.
Wherever the protective function of the forest cannot satisfy the safety requirements of modern civilization (any more), technology comes in. This is why, for many years already, protective nets against rockfall have been supplementing the protective function of the forest, or replacing it in locations where no forest exists at all.

Over the last ten years, research and development concerning such nets have been intensified substantially. New protection systems have been developed in close cooperation between the Swiss Federal Institute for Forest, Snow and Landscape Research and manufacturers. It has been possible to increase the energy absorption capacity as the most important criterion for the nets by a factor of 10. The consequence of this was that the purchasers of these protection systems saw themselves confronted by new or modified products at frequent intervals. An assessment of the effectiveness of the nets purely on the basis of works plans is not possible because calculatory proofs cannot yet be established at this stage. Although individual manufacturers were able to present results of tests, the different types of structures could not be compared, with the effect that the purchasers felt insecure. Surveys in 1997 and 1998 among experts revealed an urgent need for action. Neutral and objective testing of the protective nets was demanded.

Development of the type classification started in early 1999 after clarifications had confirmed feasibility. A stringent, but fair type classification was created with the involvement of industry, research and various authorities. The two main elements are the new test site «Lochezen» in Walenstadt/SG (Switzerland) and the present Federal Guideline. The official opening of this first European test site on 31 May 2001 marked also the start of the type classifications.

In this way the persons responsible for safety in communities, cantons, railway and road authorities are provided with a valuable decision aid that enables them to find the best solution for their rockfall problems.

In the development of the type classification it was necessary for competing companies and many cantonal and federal offices to cooperate closely. This was no easy undertaking. The result is a product which represents an important module in the coping with natural hazards and which can optimally supplement the protective function of the forest. We are grateful to the persons of the working group which implemented this guideline for their dedication and perseverance.
1 Introduction

In Switzerland, the significance of protection against rockfalls is currently increasing rapidly. Over the last years more and more protective nets against falling rocks and blocks have been erected along traffic routes and for the protection of settlements. At the same time these protective measures underwent an intensive technical development. It has been possible to increase their ability of absorbing energy by a factor of more than ten. It is difficult, however, to assess and compare the quality and performance of the different products available on the market. Calculations such as the ones applied to avalanche prevention structures are not possible at this time. In this situation the competent authorities and experts had to decide on the purchase and use of protective nets concerning which they had no exact information. With the introduction of an approval subjecting the different products to a stringent field test, the persons in charge can be provided with an important basis on which to make their decisions. The different products become comparable. The institutions entrusted with the investigation guarantee an objective and independent assessment.

The present guideline defines a standardized test sequence. It also specifies limit values that must be met by the tested products. Apart from this, however, the guideline extends beyond the core of the approval and contains some explanations closely connected to the approval. The purpose of this is to enhance the comprehensibility and to provide the association with the surrounding aspects.

The guidelines are issued on the basis of Article 39, paragraph 3 of the Order on Forests. They serve for a uniform application of the law and interpretation of Art. 39 of the said Order. Implementation authorities abiding by the instructions on execution can rely on proceeding in compliance with regulations. By deviating from the instructions, on the other hand, they run the risk of being unable to prove to the federal authorities that their chosen solution is in conformity with the law.

The Swiss Agency for the Environment, Forests and Landscape keeps a list of the approved rockfall protection kits. This list is updated continuously and published under the following address: http://www.buwal.ch/forst/sn/d/typenliste.htm
2 Purpose of the guideline

The effects of rockfalls onto protective nets vary considerably. Unknown factors are frequently encountered and can never be eliminated entirely despite careful observations and measurements. The user of the guideline must be aware of the high demands to which he/she is subjected in this sense.

The guideline is intended to meet the following higher-ranking objectives:

- Definition of the approval sequence.
- To provide a basis enabling an objective comparison of different rockfall protection kits of the same energy category.
- Improvement of the effectiveness of rockfall protection kits.
- To provide a useful aid to the persons in charge of project work, construction and maintenance of the protective devices.
- To create the prerequisites for subsidizing of rockfall protection kits.

The guideline supplements particularly the SIA Standard 160 «Influences on bearing structures» and the guideline «Influences on rockfall protection galleries» of the FEDRO/SBB, issue 1998.
3 Delimitation

3.1 Scope of application

The present guideline refers only to protection measures in the form of nets designed for the purpose of stopping falling rocks/blocks, i.e. measures belonging to the category of active protection against rockfalls.

Among the items to be protected may be roads, railway lines, paths, buildings, infrastructure objects, etc. This makes it clear that the potential users are primarily central and local governments. Apart from these, however, owners and usufructuaries of objects exposed to dangers can also be concerned by the issue.

The approval is intended for rockfall protection kits which are subsidized in Switzerland by the government.

3.2 Other protective measures

Depending on the locally prevailing circumstances, the degree of danger and the events to be expected, other measures can also be taken in the interest of an active protection from rockfalls.

These may be, a.o.:

- Fences of wire mesh
- Stockades (palisades) of timber or steel
- Stone walls
- Earth embankments
- Galleries of concrete
- Tunnels

Another possibility for protection from rockfalls is warning systems of all kinds. Such other protection measures are not the subject-matter of the approval.
3.3 Other standards and guidelines

- SIA Standard 118 General conditions applying to construction work
- SIA Standard 160 Influences on bearing structures
- SIA Standard 161 Steel constructions
- SIA Standard 162 Concrete constructions
- SIA Standard 191 Prestressed ground and rock anchors
- SIA Technical Leaflet 2010 Untensioned ground and rock anchors
- Guideline for Avalanche Prevention Structures in the Avalanche Starting Zone, issue 1990 supplementation 2000, SAEFL and WSL
- FEDRO Guideline for ground and rock anchors
- Guideline «Influences on rockfall protection galleries», issue 1998 of FEDRO and SBB
- Documentation «Planning, construction and maintenance of protective galleries against rockfalls and avalanches», issue 1998 of FEDRO and SBB
- AFNOR, French standard, «Protective equipment against rockfalls, net covers» of December 1996
- GEAM, Italian guideline for the classification and technical approval of rockfall protection structures with nets (draft)

Applicable, furthermore, are the standards concerning the materials employed, their treatment and the types of work (in particular with respect to anchorages).

SIA, V104 / 2-5, Recommendation issue 1999 (working document in extended discussion phase): Auxiliary means for calls for tenders and quotations in the areas of forest and natural hazards.
4 Tasks of the involved experts

4.1 General

Events of rockfalls can occur due to a natural erosion process (freeze/thaw periods, root pressures, etc.) or as a result of vibrations (earthquakes, detonations). Common to all of these is usually the unpredictability of time, location and intensity of the event. A task of all involved, therefore, is to select the optimal measure between sporadic and continuous monitoring, alarm systems, rockfall protection kits, stockades, embankments and galleries. The concepts for appropriate measures should permit to find an integral and comprehensive solution to the problems. Normally it is necessary to adopt a multi-stage procedure. The entire spectrum of measures (variants) must yet be dealt with at the stage of preliminary studies. At the preliminary project and detail project stages, a concept for measures is treated and put into concrete form.

4.2 Client

The client defines the objectives (purpose) of the protection measures and the utilization, i.e. he provides the fundamentals for the utilization plan. If appropriate, he adjusts these on the basis of the concept determined by the author of the project and by the authorities, to the technically and economically available resources.

4.3 Expert

The expert advises the client concerning the risks of falling rocks and blocks. He assesses possible processes and consequential effects. The expert defines the process space and reveals the ranges, masses, velocities, energies, leap heights, leap distances in possible events. He estimates the probability and the possibly determinable recurrence periods of the different event parameters. For this purpose the damage potential in respect of material and human values is established and the existing protection deficit is stated. He advises the client on possibly required protection structures and, depending on the circumstances, he points out residual risks and the limits in the effectiveness of rockfall protection kits, i.e. he provides the fundamentals for the safety plan.
4.4 **Author of the project**

The author of the project
- determines the concept underlying the measures and advises the client with the support of the expert
- informs about the necessary adjustments of the objectives of the protection measure and the residual risks
- establishes the utilization and safety plan
- gives the reasons for the decision in favour of a rockfall protection kit rather than other measures
- determines the final rockfall protection kit
- calculates the static equivalent loads on the basis of the approval
- submits proof of the bearing safety of the foundations and anchorages and establishes their suitability for the purpose
- supplements the project with accompanying measures such as afforestation, protective embankments, blasting of blocks, etc.
- presents the accessibility
- advises the client in the preparation of a monitoring and maintenance schedule
- determines the cost of the project and of its maintenance
- prepares a comprehensive report with the necessary documentation

4.5 **Supplier**

The supplier delivers all documents required to build and maintain the offered construction. The following proofs must be submitted, in particular:
- The report on the approval, i.e. on the approval of the construction
- Details of foundation and anchor forces
- Test certificates for the individual components such as corrosion protection, tensile tests, etc.

4.6 **Building contractor**

The responsibility of the building contractor is prescribed in the SIA Standard 118.
4.7 Government authorities

The federal government issues guidelines and recommendations within the framework of its obligations under the law. It grants the approval for the tested rockfall protection kits.

The cantonal authorities are responsible for the translation of the guidelines and recommendations as well as the application of the list of available rockfall protection kits.

The cantonal and federal authorities can advise the client and support the author of the project. Hereby they represent the public interest, particularly in the definition of the objectives of the protection measures and the concept underlying the measures. They decide on the subsidizing of measures and grant the necessary permits and approvals.

4.8 Commission and Federal Research Institute

The Federal Expert Commission on Avalanches and Rockfall (FECAR) and the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL) advise the authorities in matters of principle and special questions. The approval of rockfall protection constructions is carried out by them jointly (cf. 6.1 Administrative procedure).
5 Definitions and designations

5.1 Organizations

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<th>Acronym</th>
<th>Description</th>
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<td>Federal Department of Environment, Transport, Energy and Communications</td>
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<tr>
<td>FECAR</td>
<td>Federal Expert Commission on Avalanches and Rockfall</td>
</tr>
<tr>
<td>FEDRO</td>
<td>Federal Roads Office</td>
</tr>
<tr>
<td>FOT</td>
<td>Federal Office of Transport</td>
</tr>
<tr>
<td>SAEFL</td>
<td>Swiss Agency for the Environment, Forests and Landscape</td>
</tr>
<tr>
<td>SFA</td>
<td>Swiss Forest Agency</td>
</tr>
<tr>
<td>SLF</td>
<td>Swiss Federal Institute for Snow and Avalanche Research</td>
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<tr>
<td>WSL</td>
<td>Swiss Federal Institute for Forest, Snow and Landscape Research</td>
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5.2 Definitions, general for rockfalls

- **Rockfall, blockfall**: Falling, leaping and rolling of individual rocks ($\varnothing < 50\,\text{cm}$) and blocks ($\varnothing > 50\,\text{cm}$), whereby the total volume does not exceed $100\,\text{m}^3$.

- **Rock avalanche**: Fall of a mass of rocks which is fractioned into blocks and stones during the fall and on impact, whereby the interaction between the components has no decisive influence on the dynamics of the process.

- **Rock slide**: Fall of very large masses of rocks displaying more or less coherence in the original rock structure, whereby high velocities are reached and the transport mechanism is characterized by an intensive interaction between the components.

- **Active measure**: Protective measure that counteracts the natural event actively to reduce the danger or to substantially alter the probability of occurrence (e.g. rockfall protection kits, rockface covers made from nets).

- **Passive measure**: Protective measure intended to reduce the damage without actively influencing the course of the natural event (e.g. development planning measures).

- **Normal event**: A normal event is a rockfall whose intensity corresponds to a recurring period of approx. 30 years. The normal event is generally defined on the basis of blocks and traces observed in the terrain.
Exceptional event  The exceptional event is characterized by the extremely rare rockfall of high intensity that is difficult to capture statistically.

5.3 Definitions for rockfall protection kits

These definitions are shown in the illustrations 1, 2 and 3.

- **Rockfall protection kit**: Construction consisting of actual nets, posts and ropes
- **Nets**: Bearing element acting as a surface. Types of nets: diagonal rope nets, orthogonal nets, flexible nets, ring nets
- **Bearing ropes**: Bearing elements serving to transmit the forces into the posts, ground plates and retaining ropes.
- **Posts**: Part of the bearing structure supporting the bearing ropes and nets. Types of posts: middle section posts, boundary posts, auxiliary posts. Materials: steel HEA, HEB, RHS, ROR, round timber
- **Retaining ropes**: Upslope ropes serving to transmit the posthead forces to the anchorages.
- **Brake elements**: Elements in ropes which absorb energy
- **Ground plate**: Part of the construction located in/on the foundation. The post and in some cases the lower bearing ropes are fastened to it.
- **Laid-on mesh**: Wire mesh fastened to the net on the upslope side
- **Anchorages**: Bearing element transmitting the rope and post forces into the ground. Types of anchorages: rod anchor, rope anchor
- **Distance between posts**: Distance between two posts
Illustration 1:
Schematic view of a deep-anchored rockfall protection kit with designation of the bearing elements

Illustration 2:
Schematic view of a rockfall protection kit with fixed posts
Illustration 3: Schematic front view with designation of the bearing elements
5.4 Definitions for the test sequence

Excursion: The excursion of the rockfall protection kit corresponds to the braking distance $b_s$ of the test body until the reversing point in the trajectory (illustration 9).

Energy category: Division of the rockfall protection kits into 9 energy categories in the sense of the test energy (chart 2).

Test energy: Kinetic energy of the test body on first contact when falling into the net (main test c) 100%.

Half test energy: Kinetic energy of the test body on first contact with the net (in part-test b) 50%.

Net height: Height $h_v$ of the net prior to a load in the centre of a section, measured at a right angle to the ground surface (illustration 4).

Residual useful height: Height $h_n$ of the net after a load in the centre of the section, measured at a right angle to the ground surface (illustration 5).

Test body: Concrete block of ashlar shape with equal edge lengths $s$, whereby the corners are flattened to one third of the edge length (illustration 10).

Illustration 4: Designations of angles and dimensions
Illustration 5: Position of the bearing ropes after an impact

Illustration 6: Front view of the bearing ropes in the middle section after an impact

LEGEND:
1: Position of the bearing ropes before the test
2: Position of the bearing ropes after the test
3: Position of the rock after the test
5.5 Designations

The majority of these definitions are shown in the illustrations 4, 5 and 6.

\( \alpha \) (deg) Post rotation = difference in the post’s inclination due to strain
\( \beta \) (deg) Angle between the post and the perpendicular
\( \delta \) (deg) Angle between the post and the right angle to the slope
\( \Psi \) (deg) Slope inclination
\( a_i \) (m) Length of the post
\( a_n \) (m) Distance between ropes = minimum distance between upper and lower bearing ropes after an impact
\( a_v \) (m) Distance between posts
\( a_s \) (m) Distance between ropes = minimum distance between upper and lower bearing ropes before an impact
\( b_e \) (m) End position of the test body after an impact
\( b_r \) (m) Brake change = length change of the brake elements
\( b_s \) (m) Length of the braking distance of the test body (measured in the video picture)
\( d_o \) (m) Sag of the upper bearing rope in the centre of the section
\( d_u \) (m) Sag of the lower bearing rope in the centre of the section
\( h_n \) (m) Residual useful height = height of net after the impact
\( h_v \) (m) Height of net before the impact measured at right angle to slope
\( l_o \) (m) Length of net between the upper and lower bearing rope after an impact (in end position)
\( l_v \) (m) Length of net between the upper and lower bearing rope before a impact
\( s \) (m) Edge length of the test body in question
\( t_s \) (m) Braking time = time taken to cover the braking distance \( b_s \)
6 Approval

6.1 Administrative procedure

The administration of the approval is in the care of the SAEFL. The Federal Office accepts the registration of the manufacturers of rockfall protection kits, initiates the inspection and issues the certificate for the individual constructions. The approval is carried out by the Federal Expert Commission on Avalanches and Rockfall and the WSL. Available for the tests is the test site «Lochezen quarry» in Walenstadt SG/Switzerland. The measurements and observations during the individual tests are recorded by the WSL and presented in a report.

The individual working steps are listed in chart 1 and explained in detail hereafter:

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<td>Application to SAEFL with documentation</td>
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<td>2 SAEFL / SFA</td>
<td>Registration, confirmation of receipt, information about the costs</td>
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<td>3 WSL</td>
<td>Viewing of the documents, organization of the tests</td>
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<td>4 Manufacturer; supplier</td>
<td>Payment of the deposit</td>
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<td>5 WSL, manufacturer, delegation of FECAR (Expert Commission)</td>
<td>Implementation of the tests</td>
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<td>6 WSL, delegation of FECAR</td>
<td>Test reports for the FECAR</td>
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<tr>
<td>7 FECAR</td>
<td>Overall assessment yes/no, application to SAEFL, brief report to manufacturer within 6 weeks of test</td>
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<tr>
<td>8 SAEFL / SFA; manufacturer; supplier</td>
<td>Final financial settlement with manufacturer; supplier</td>
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<tr>
<td>9 SAEFL / SFA</td>
<td>Sending of certificate and test report, per early June or end October each year</td>
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</table>

Re 1: The manufacturer or supplier of a rockfall protection kit sends an application approval to the SAEFL. At the same time he submits a documentation containing all necessary construction plans and detail drawings, all details and specifications of the materials to be used, and in particular, also the force/path diagrams of the brake elements.

Re 2: The SAEFL registers the application and documentation. In agreement with the WSL it informs the manufacturer on the next steps, the dates and the costs. Remittance of the deposit payment is requested at the same time.

Re 3: The WSL examines the documentation, checks the general conditions concerning the installation of the construction at the test site and organises the tests.

Re 4: The manufacturer pays the deposit and is subsequently requested to install his rockfall protection kit.

Re 5: The WSL and a delegation of the FECAR carry out the tests with the inspections and measurements and record the individual working steps and results.

Re 6: The WSL edits a report on the measurable tests (tests a, b and c), and the delegation of the FECAR report on the findings in their expert opinion (test d).

Re 7: The FECAR assesses the results, lodges its application concerning approval of the rockfall protection kit with the SAEFL and informs the manufacturer.

Re 8: The SAEFL prepares the final invoice.

Re 9: The SAEFL decides on the approval of the rockfall protection kit and sends the test report and the certificate to the manufacturer.
6.2 Requirements applicable to the rockfall protection kits

6.2.1 Principles

In principle the task of a rockfall protection kit is to stop moving rocks and blocks. In the natural environment this is often achieved with the aid of a ground contact during deceleration. This means that the protective construction takes up only a part of the kinetic energy of the rock, while the other part is absorbed by the ground.

The rockfall protection kits to be tested in accordance with this guideline should be able to absorb the full kinetic energy of a test body falling onto them vertically. Thus the kinetic energy corresponds to the one of the energy category in question. The maximum elastic and plastic deformations of the construction must not exceed a certain value.

The effective surface of a rockfall protection kit should remain as large as possible also after an event and be impaired as far as possible in its height only. Specific demands are imposed as far as the residual useful height of the construction is concerned.

The effective width must not be interrupted after an event.
6.3 Test facility Walenstadt / Switzerland

6.3.1 Geographic situation

The test site is located in the Lochezen quarry, approx. 200 m above the Walensee. Access is over a funicular railway with a bottom station approx. 2 km westward of Walenstadt and can be reached by lorry. Installation of the rockfall protection kits in the terrain is carried out by a firmly installed crane (illustration 7).

Illustration 7: Schematic view of the test setup in Walenstadt with crane, rockfall protection kit and video camera. Deformation of the rockfall protection kit after a test

6.3.2 Installation of the rockfall protection kits

The rockfall protection kits are installed at a height of 15 m, whereby the posts are fastened in four foundation positions and deep-anchored in the rock face by ropes. The inclination of the posts is 30° in relation to the horizontal plane; that of the retaining ropes approx. 40° (illustration 8).
The rockfall protection kit consists normally of three sections with a distance between posts of 10 m. Installed, therefore, are 4 posts and 3 nets between them (illustration 3).

The lengths of the posts depend on the energy category in question (chart 2). The tests are carried out with these minimal lengths of posts. Once the tests are passed, however, the manufacturers are allowed to offer posts up to 1.5 times longer than the tested ones, whereby proof of the posts' bearing safety must be submitted.

Illustration 8: Arrangement of the rockfall protection kits in the test setup. Angles of the individual bearing elements

6.4 The individual tests

The rockfall protection kits are divided into 9 categories for energies from 100 kJ to 5,000 kJ. These energies are also referred to as test energies. A construction must pass the various part-tests a) to d) of its energy category, whereby different requirements apply. In the case of tests a) to c) the construction is subjected to individual tests with test bodies, while test d) consists of a qualitative assessment of the rockfall protection kit and of the supplied documentation.

The tests a) to d) are described individually in the chapters hereafter.
6.4.1 Preliminary tests a) with small energies: (boundary section)

**Main objectives of this test:**
This preliminary test serves on the one hand to check the deformations of the laid-on mesh, while on the other only a few ropes or rings of the net are to be strained with the smaller test bodies.

**Implementation method:**
The test bodies listed below are dropped together per size category into a boundary section at an impact velocity of 25 m/s.
- 5 small test bodies 10/10/10 cm, total mass 12 kg, energy 3.8 kJ
- 3 small test bodies 20/20/20 cm, total mass 59 kg, energy 18 kJ
- 1 test body* of 50/50/50 cm, mass ≈ 300 kg, energy 94 kJ
  * The rockfall protection kits of energy category 1 and 2 are not tested with this test body

**Measuring and observation methodology:**
The deformations of the laid-on mesh and of the affected net components are measured and described per size category of the rocks.
Damages to individual wires or ropes are recorded.
No force measurements are made.

**Demands imposed on the rockfall protection kit:**
The test bodies must be slowed down by the rockfall protection kit.
No punctures are allowed to take place.
No repair work is allowed between the individual throws.

6.4.2 Preliminary test b) with energy 50 %: (middle section)

**Main objectives of this test:**
This test serves to establish the required repair effort, the service-friendliness of a rockfall protection kit and the braking distance at half the energy.

**Implementation method:**
The test body envisaged for this energy (chart 2) is dropped into the centre of the middle section at an impact velocity of 25 m/s.

**Measuring and observation methodology:**
Prior to the test, the positions of the individual bearing elements are measured and recorded.
During the test, the tensile forces on the ropes are measured and recorded at approx. 10 anchor points.
The test is filmed from two directions.
The following values are recorded after the test:
- Deformations of the ropes, brake elements, posts and nets
- The height (altitude) of the test body
- Damages to the individual bearing elements
The hours and material required for repairing of the rockfall protection kit are recorded.
The braking time $t_s$ and the maximum braking distance $b_s$ as far as the bottom reversing point of the test body are determined from the video pictures (Fig. 9).
Demands imposed on the rockfall protection kit: The test body must be stopped by the rockfall protection kit. No puncture is allowed to take place. The least possible repair effort is required.

6.4.3 Main test c) with energy 100% (middle section)

Main objectives of this test: In this test the full service kinetic energy of the test body is to be transformed into deformation work of the rockfall protection kit. Thus, both the bearing capacity and the deformability are to be tested.

Implementation method: The test body envisaged for this energy (chart 2) is dropped into the centre of the middle section at an impact velocity of 25 m/s.

Measuring and observation methodology: Prior to the test, the positions of the individual bearing elements are measured and recorded. During the test, the tensile forces on the ropes are measured and recorded at approx. 10 anchor points. The test is filmed from two directions. The following values are recorded after the test:
- Deformations of the ropes, brake elements, posts and nets
- The height (altitude) of the test body
- Damages to the individual bearing elements

The braking time \( t_s \) and the maximum braking distance \( b_s \) as far as the bottom reversing point of the test body are determined from the video pictures (Fig. 9).

Demands imposed on the rockfall protection kit: The test body must be stopped by the rockfall protection kit. No puncture is allowed to take place. The maximum braking distance \( b_s \) must be shorter than the value specified in chart 2.

After the impact, the height \( h_n \) of the net in the middle section must amount at least to the value specified in chart 2 (measurement before removal of the test body).

6.4.4 Assessment d) of the rockfall protection kit according to special criteria

Main objectives of this test: This test concerns primarily the assessment of criteria which are not measurable and the practical suitability of the rockfall protection kit.

Implementation method: Assessment of the documentation:
- Comparison of the dimensions in the plans with those of the rockfall protection kit. It must be guaranteed that the supplied documentation corresponds to the installed rockfall protection kit.
• The manufacturers must state the applicable standards that are met by their product (in particular the standards for protection against corrosion, steel wires and wire rope clamps).

Assessment of the construction:
• The actual installation is observed and compared with the installation instructions, keeping in mind the prevailing special circumstances.
• The simplicity of the construction is assessed and its adaptability to the natural terrain is estimated.
• The useful life of the rockfall protection kit is assessed on the basis of the life span of the individual components as substantiated by the supplier.

Requirements:
Plans and actual construction must correspond in all details.
Compliance with applicable standards.
The installation instructions should be practical and correspond to reality.
Unsophisticated designs should have positive effects on the sales price.
A long useful life should be aimed at.

Illustration 9:
Positions of the test body during the tests b) and c). The length of the net is measured in pos. 3
Chart 2:
Details of the test parameters in part-tests b) and c)

<table>
<thead>
<tr>
<th>Category</th>
<th>Length of post (m)</th>
<th>Part-test b) (50 %)</th>
<th>Part-test c) (100 %)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Energy (kJ)</td>
<td>Mass of test body (kg)</td>
<td>Edge length s (m)</td>
</tr>
<tr>
<td>1</td>
<td>1.5</td>
<td>50</td>
<td>160</td>
</tr>
<tr>
<td>2</td>
<td>2.0</td>
<td>125</td>
<td>400</td>
</tr>
<tr>
<td>3</td>
<td>3.0</td>
<td>250</td>
<td>800</td>
</tr>
<tr>
<td>4</td>
<td>3.0</td>
<td>375</td>
<td>1'200</td>
</tr>
<tr>
<td>5</td>
<td>4.0</td>
<td>500</td>
<td>1'600</td>
</tr>
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<td>6</td>
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<td>750</td>
<td>2'400</td>
</tr>
<tr>
<td>7</td>
<td>5.0</td>
<td>1'000</td>
<td>3'200</td>
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<tr>
<td>8</td>
<td>6.0</td>
<td>1'500</td>
<td>4'800</td>
</tr>
<tr>
<td>9</td>
<td>7.0</td>
<td>2'500</td>
<td>8'000</td>
</tr>
</tbody>
</table>

Illustration 10:
Shape and geometry of the test bodies of reinforced concrete
6.5 Test report

The test report contains all important data and the protocols (records) of the tests a) to d) that may contribute to the decision on the approval. The protocols are individually listed hereafter:

- Dimensions of the rockfall protection kit and schematic view of the arrangement in principle of the individual parts of the bearing structure.
- Protocol on test a): This consists of a verbal description of these tests.
- Protocols on test b): These contain the data on the geometry changes, force measurements, evaluations of video pictures and the compilations concerning the repair effort.
- Protocols on test c): These contain the data on the geometry changes, force measurements, evaluations of video pictures and a compilation concerning the occurred damages.
- Protocols on test d): Verbal description of criteria that are not measurable.

6.6 Costs of the test

The costs of testing a rockfall protection kit are made up of a basic lump sum and a daily lump-sum charge as per separate sheet of the SAEFL. They include the use of the lift and crane equipment for installation and removal of the construction, the depreciation of the measuring devices and instruments plus the editing of the test report.

Also included are all expenses of the FECAR and the SAEFL.
7 Foundation

7.1 Requirements

In the case of rockfall protection kits only the parts of the bearing structure above ground are tested on the basis of this guideline. Here, forces result which the foundations and anchorages have to transmit to the substrate. Adequately dimensioned foundations and anchorages of a suitable bearing capacity are a prerequisite for proper functioning of these tested rockfall protection kits in the field. Highest importance, therefore, must be attached not only to the project work for the foundations and anchorages, but also to the execution on the building site of these critical parts of the bearing structure.

7.2 Foundation and anchor types

With rockfall protection kits against rockfalls, the circumstances applicable to foundations and anchorages are product-dependent. This means that only the general arrangements can be dealt with within the framework of this guideline. Different foundations and anchorages will be used depending on the substrate and the construction concept. In general, however, it is possible to differentiate between the anchorages and foundations of the posts on the one hand and the anchorages of the ropes on the other. The most important foundation and anchor types are presented hereafter.

7.2.1 Foundations of the posts

At the base of the post it must be ensured that the decisive pressure and thrust forces can be transmitted into the substrate. If additional strains due to torques occur in constructions that are not deep-anchored, the foundation construction must be able to transmit these also into the substrate.

7.2.2 Anchorage of the ropes

The anchoring ropes are normally attached to wire rope anchors or rod anchors. Since the orientation of the rope force and the direction of the anchorage correspond only very rarely, transverse forces will occur in the transition area between anchor head and substrate. Depending on the size of the deflection angle on the one hand and on the mechanical strength of the basic material on the other, the transverse forces cause different flexural strains in the anchor material.
7.3 Dimensioning of the foundations and anchors

There is no reliable method of precisely calculating the forces on foundations and anchorages that result from the conversion of the kinetic energy of a rock into deformation energy of the construction. This is why, for dimensioning the foundations and anchors, one relies on the force measurements resulting from the approval tests. On account of the vertical fall of the test body, the braking forces at the rock, at braking times between 0.3-0.9 s, are increased by approx. 10-25 % in relation to horizontal braking. Depending on the time course of the braking force even bigger differences may occur.

7.3.1 Safety factor

The forces measured in the approval include not only the more stringent conditions of the vertical drop, but also the compensating effects of the central position in which the test bodies impact the net. Eccentric strains nearer the posts or nearer the bearing ropes will subject individual ropes to additional forces which are not yet known.

It is on these grounds that the measured maximum forces resulting from the main test c) with 100 % energy must be increased by 30 %. These increased forces are then to be introduced in the further calculations as static equivalent loads.

\[ \text{Static equivalent load} \ Q_e = \text{measured force} \ F_{\text{max}} \times 1.3 \]

7.3.2 Bearing safety and suitability for use

The effect of the static equivalent load \( Q_e \) corresponds to the characteristic value \( Q_r \) as per the SIA Standard 160, clause 3 23 2. It is regarded as the leading effect and the dimensioning value \( Q_d \) is determined by:

\[ Q_d = y_Q \cdot Q_r \]

\( Y_Q \): Load factor for the leading effect \( y_Q = 1.3 \)

\( Q_r \): Characteristic value of the effect \( Q_r = Q_e \)

The requirements in respect of the suitability for use and the effects for their proof must be defined jointly by the author of the project and the client. In many cases the requirements are adequately covered by the proof of the bearing safety.
7.4 Anchor mortar

The quality of the mortar used for the anchors plays a decisive role in the anchorage of a protective construction against rockfalls. In the case of avalanche prevention structures this quality assurance aspect is defined in the «Guideline for Avalanche Prevention Structures in the Avalanche Starting Zone», issue 2000 (publisher: SAEFL, Swiss Forest Agency, CH-3003 Bernee and WSL, Swiss Federal Institute for Snow and Avalanche Research, CH-7260 Davos-Dorf). This guideline is declared as compulsory also for the use of anchor mortar for foundation and anchorage purposes with rockfall protection kits against rockfalls. Below are excerpts of the most important facts from the mentioned guideline.

7.4.1 Basic aspects

Proof of the suitability of an anchor mortar must be submitted by means of a suitability test. This test must be carried out by a neutral laboratory. The last suitability test and the pertaining report must not be older than three years.

During the stabilizing work on the building site the conformity of the applied mortar must be tested continuously. The frequency of testing must be adjusted to the quantity of mortar processed and specified so that the actual disperson of the mortar properties is recorded. The tests must be carried out in a neutral laboratory.

7.4.2 Testing for suitability

The suitability test is made on mortar of a pumpable consistency. The test must comprise the following inspections:
- Properties of freshly-mixed mortar: setting and spreading dimensions, air entrainment and raw density
- Tests on solidified mortar: raw density, tensile strength in bending and compressive strength, elasticity measurement, frost resistance, longitudinal change (shrinkage)

The afore-mentioned guideline lists the detailed requirements on the mortar as limit values.

7.4.3 Conformity tests

Removal of the mortar sample and production of the test specimens are executed on the building site. From the normally produced mixer charge, a sample is taken at the end of the pump hose during the stabilization work and the following test specimens are made:
- either 9 prisms 40/40/160 mm
- or 2 cylinders Ø = h = 200 mm
- or 2 cubes 200/200 mm or test specimens of a similar volume
The specimens must be marked clearly and permanently. Care must be taken that a loss of moisture is prevented and that a temperature of at least 10°C is guaranteed. Transport to the test lab must be carried within no more than 2 days.

The following information must be supplied to the test lab together with the test specimens so that the test values can be interpreted with certainty:

- Client
- Protocol of mortar production
- Air and mortar temperature at the time of production
- Point in time of form stripping
- Storage conditions

The conformity test must comprise the following investigations:

- Raw density and compressive strength after 7 and 28 days
- Determination of the frost resistance

The afore-mentioned guideline lists the detailed requirements on the mortar as limit values.
8 Effective date

This guideline comes into force on 1 June 2001.
9 Transitional provisions

During the transition period from 1 June 2001 until 1 June 2003, rockfall protection kits that have not gained the approval of the SAEFL may still be used in projects subsidized by the Swiss Confederation.

However, the supplier shall submit proof of the bearing safety and of the suitability for use, together with a pertinent confirmation from a neutral authority.

Recommended are rockfall protection kits which have been tested so far under the supervision of the WSL.

After expiry of the transition period the Swiss confederation will only subsidize measures and projects containing tested and approved rockfall protection kits.
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