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Certification of Rock fall Barriers in Europe

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Abstract: Since their first application in 1958 at Brusio, Switzerland, rock fall barriers made out of steel wire rope meshes have proved as a powerful mean for rock fall mitigation along highways all over the world. Nevertheless, no technical standard did exist either for their construction or for their technical approval so far. This situation made it difficult for designers as well as for clients to compare the different systems as for their safety and select an appropriate product for their applications. Therefore, the European Organization for Technical Approval (EOTA) is establishing a guideline for testing and certification of rock fall barriers as a first step to harmonization of rockfall mitigation within the European Community. The actual draft is presented within this paper.

The intended approach by defining certain energy dissipation levels and having the producer selecting the corresponding energy he wants his system to be tested is described. The state of the discussion as for the type of tests - drop tests or launch tests - is commented. Criteria for the assessment of the required performance of barriers under different energy levels are presented. Their practical applicability is analyzed. The minimum required number of tests as well as the desired hit areas are discussed. The pros and cons of testing not only the center of the middle panel but also the edges and the posts are presented. The practical meaning of the expected test results is analyzed from the point of view of a designer.

Introduction: In the eighties of the last century there were a lot of different rockfall barrier types, but their energy dissipation capacity was in general unknown. Only very few producers were using tests for the systematic development of their barriers, like BRUGG CABLE PRODUCTS - the later GEOBRUGG - and ISOFER, both in Switzerland (SPANG & BOLLIGER, 2001). RITCHIE's (1963) pioneering rock rolling tests intended more to establish criteria for the determination of fence heights than to analyze their energy dissipation capacity. COLORADO DEPARTMENT of HIGHWAYS (1989) tests have brought some fresh ideas into rockfall mitigation, but were not systematic enough to fill that gap. Thus CALTRANS tests at Big Sur, Ca. were the first systematic and independent field tests to compare barriers of different producers - in this case ENTREPRISE INDUSTRIELLE from France and GEOBRUGG from Switzerland (SMITH & DUFFY, 1990) and to determine their energy dissipation capacity by identical and reproducible tests.

On the other hand, the specific kinetic energy to be dissipated at a certain location, where such a structure had to be erected, could not be determined, too, no realistic computation method being available. This situation resulted in purely empirical designs with unknown safety factors (SPANG, 1988). It changed when the first reliable rockfall simulation programmes became available in the market.

State of the art of testing rockfall barriers: The actual situation is characterized by the following facts:

- A lot of rockfall barrier systems are now tested as for their energy dissipation capability, but partly by the producers themselves, by different test procedures, different energies, mass/ velocity ratios, different sizes of blocks, with or without rotation, by rock rolling, vertical drop tests, launch tests, pendulum tests, or other more exotic test procedures, targeting into the center of the panel, on the posts, on the lower border etc. etc. (HALLER & GERBER, 1998). This wide range of different test approaches does not mean more than an evident lack of comparability of their results.

- Until December 2001, when the SWISS AGENCY for the ENVIRONMENT; FORESTS and LANSCAPE published its "Guideline for the approval of rockfall protection kits" not any regulation or recommendation for the execution of these tests did exist, worldwide.

- It is well known by the scientific community that the energy dissipation of a system depends on many different factors and that the result of tests depends on the boundary conditions of the impact on the barrier. Especially it depends on:

  - The **number of panels**, a test barrier consists of. Most systems transfer a considerable amount of the impact energy to the neighboring fields resulting in a higher flexibility of the system, a bigger mass to be accelerated and a longer restitution time reducing the brake forces inside the retaining ropes and the foundation.

  - The **location of the impact** on the surface of the panel: the center of the panel has the highest flexibility and symmetry and shows considerable higher energy dissipation than the corners, the boundaries or the posts, for examples. The order of magnitude in the energy dissipation may range between 100 % in the center and 60 to 70 % in the corners. Because no systematic tests have been carried out so far, the distribution of the energy dissipation over the panel surface is not known. Thus, tests with different target areas can't be compared. Obviously, tests only in the center of a barrier will not give reliable numbers for a safe design.

  - The relationship between **barrier height and energy dissipation** capacity: The interdependence of barrier height and energy dissipation is not known. Thus, tests of barriers with different heights are not comparable.

  - The influence of **angular velocity**: In the early days of rockfall testing, rock rolling was the mostly applied method. There is no doubt it is the most realistic one, too, because it includes rotation of the rock. Most of the modern test methods are restricted to impacts with pure translation. Rotation may represent up to 30 % of the total kinetic energy of a real rockfall and the mechanism of energy transfer from the boulder to the barrier should be significantly different for the translational and for the rotational part of the kinetic energy. This was one of the most interesting lessons to be learned from the first CALTRANS tests in 1985 (SMITH and DUFFY, 1990; SPANG & BOLLIGER, 2001). Tests with pure translation may be comparable amongst themselves, but they will be of no practical use for the decision for a certain system in design.

  - The kind of **loading:** It should be trivial, that static loading of entire systems or parts of systems will not give any reliable ideas on the behavior of a barrier under dynamic impact. The reason is that the forces developing inside a system under dynamic loading depend on the brake time, which can't be predicted from theoretical considerations. Thus, these tests are without any use for design decisions.

  - **Mathematical model:** In spite of the fact that increasing scientific capacities are involved, there is no calculation method available to substitute, control or amend field tests, actually. Thus, no method does exist to calibrate results of different test methods.

- On the other hand, the actual situation is characterized by a rapid and ongoing development of rockfall simulation programmes. Therefore, it is state of the art to determine the probable kinetic energy and bounce height of a rock at the location of a rockfall barrier under design and to demand these values in the technical specifications of the tender documents (SPANG & KRAUTER, 2001). Such a requirement is useless, if there is no reliable resp. common quality standard to compare the resulting tenders as pointed out above.

European approach to standardization: As for the specific situation in Europe, many of the member states of the European Community have mountainous areas and have to cope with rockfall risks. Only few countries have their own rockfall barrier systems resp. production, however, and sell their systems to the others, or even distribute them worldwide. To make systems comparable, make the market more transparent and define equal safety standards a standardization of test procedures within the European Community obviously was urgent - not a standardization of the systems themselves. To archive this purpose the European Commission as the executive power of the member states gave a mandate to the European Organization for Technical Approval (EOTA) to establish a European Technical Approval (ETA) guideline on rockfall barriers. A system tested according to this guideline will be granted an ETA that means it is fit for the intended use.

Aim of the guideline: The guideline shall be applicable to all rockfall barriers consisting of posts, cables and nets, independent from their specific structure, whether the nets are linked to suspension cables or and directly to the posts, whether the posts are exposed to rockfall or protected by the net.

There is a vivid and lasting discussion amongst the members of the working group about the purpose of the intended tests in conjunction with the test installation. The one group favors the restriction to the pure comparability of test results as the only aim, the other, consisting mainly of public customers, designers and this author, argues for tests determining limit energy dissipation and maximum elongation as a base for design decisions and approval of tenders. This is amazingly not the same, because for comparison only, it doesn’t matter which tests are executed as far as they follow the same procedure and their results being reproducible.

For design purposes it is vital to know the lowest amount of energy a system can dissipate under the most unfavorable conditions and at the most unfavorable location, should it be a hit on a lower or upper corner, assuming that the both sides show the same behavior because of their symmetry, or on a post at the foot, where the system might be the most rigid, or against the top, where the bending moment reaches its maximum. There are also systems collapsing when a retaining rope is hit. The argumentation of the first group concentrates on limitation of test cost, believing that determination of the limit energy dissipation would require a bigger number of tests and overtax small producers. By the way, they lobby for already existing test sites with ropeway installations, where the variation of targets requires the shift either of the ropeway or of the barrier, whereas a crane can easily drop a boulder at any desired point of the barrier. To this author’s opinion as a designer it would be spoiled money to make tests to whatever extend, if they don’t give the numbers needed for the selection of products during design and tender. This should be the first aim of any regulation and not a “l’art pour l’art” comparison.

lfd. Nr.	Test proce-dure	Example	Accurancy of selected hit	Variation of hit area	Variation of impact angle	Angular velo-city of boulder	Variation of kinetic energy	Conformity with reality	cost of installation	(examples) for installations	Reproducibility for test results	Rating	Posi-tion
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	Rock rolling - flat slope	SMITH & DUFFY (1990)	3 (not controlled)	2 (by chance)	3 (not possible)	1	3	1	1	Shayupin, Taiwan / Big Sur, Ca.	3	17(-)	4
	- steep slope		3 (not controlled)	2 (by chance)	2 (not controlled)	1	2 (accuracy suffers with increasing path length)	1	1	Oberbuchsitten, Ch.	3	15(+)	2
2	Launch test	HALLER/ GERBER (1998)	2	3 (barrier or ropeway has to be shifted)	3 (inclination of barrier to be changed)	2 (difficult)	1	3 (with rotation)	3	Beckenried, Ch.	2	19(-)	5
3	drop test	HALLER & GERBER (1998)	1	1	3 (inclination of barrier to be changed)	2 (difficult)	1	3 (without rotation)	2	Walenstadt, Ch. Itsukaitchi, Jp.	1	14(+)	1
4	Pendulum test	COLORADO DEPT. HIGHWAYS	1	1	2 (inclination of barrier to be changed or distance between barrier and crane varied)	3 (practically not feasible)	3 (upper limit by stability of crane)	3	1	Colorado, USA	1	15(+)	3
5	Vertical sums	/	10	9	13	9	10	11	8	/	10	80	
6	Average	/	2	1,8	2,6	1,8	2	2,2	1,6	/	2	16	

Fig. 1: Pros and cons of different test installations

As shown by Fig. 1 the type of test installation has a decisive influence on the kind of tests that can be executed. According to the selected criteria and the given ratings, drop tests proved superior to the others. Drop tests are prescribed by the above-mentioned Swiss guideline, too.

Actual state of guideline: After its 7th session the working group agreed on the following propositions:

- The **test scale** shall be 1:1. No model laws do exist so far to enable tests at a reduced scale.

- The **height** of the tested barriers shall be correlated to the tested energies. This rule is reasonable, because kinetic energy and size of a block are correlated and there should be a sound relation between the size of a block and the height of a barrier, not exceeding a ratio of 1:3.

- **Width of panel:** It is known since the first tests at Oberbuchsitten in Switzerland, executed by ISOFER in 1988 (SPANG & BOLLIGER, 2001), that the flexibility and subsequently the energy dissipation capacity of a barrier increases with increasing width of the panels resp. with increasing distances between the posts. Actually, a distance of 10 m can be considered as a standard. The working group decided to let the decision on the width of the panels to the producer, who will get his certification for the tested width only. Because there is no reliable correlation between the energy dissipation capacity and the height or width of a system, the producer will be forced to order separate tests for any of the heights and widths of his barriers he wants to have certified. This will lead to the introduction of standard widths and standard heights on the market, because no producer will invest the money to have all possible combinations tested. From the point of view of this author, this is acceptable.

- The **number of panels** shall be three. This is because most of the systems transfer a considerable amount of energy to neighboring fields. Three panels - the one to be hit in the middle - is a good compromise between the consideration of this load transfer and cost of tests.

- **Angles of impact:** The trajectory of the block shall be inscribed in a vertical plane orthogonal to the straight line, connecting the base of the posts. The angle between the net plane defined by its four edges and the trajectory at the moment of the impact shall be between 70 and 90°.

- A squat regular **block** with 26 areas defines the geometry of block. The size of the block shall be not larger than one third of the height of the barrier. Tabular or other geometries are not tested.

- **Densit**y resp. material of the block is defined by reinforced standard concrete resp. by a density of 2.5 g/cm³.

- **Translational velocity** at the moment of impact shall be between 25 and 30 m/s, this range being frequently observed in nature. There is a discussion to link the velocity to the energy level, described below. The lower velocity shall be linked to the lower energy. To the opinion of this author, there is no reasonable argument to do so. If you are dealing with a natural rock slope, the level from which the blocks may start will be independent from their size. The only difference will be that the frequency of smaller blocks will mostly be much higher than that of the big ones. It would be more realistic to define one velocity only, independent from energy levels.

- **Angular velocity** is not considered. According to the experience of this author, this will lead to a serious limitation in the applicability of the test results in design. An impact without a considerable angular velocity is restricted to free falling blocks hitting the barrier without any previous surface contact. In all other cases of rolling or bouncing rolling itself or the necessarily eccentric impacts will accelerate the block around an axle and result in an angular velocity. The percentage of the rotational kinetic energy can be more than 30 % of the total kinetic energy. This is too much for being neglected. Neglecting the angular velocity might be acceptable as a first step, resulting from the difficulties of actual test installations in modeling angular velocities, as presented by fig. 1. Triggering angular acceleration is possible by rock rolling or by launch tests, if the block impacts on the ground before hitting the barrier. The low reproducibility of rock rolling tests could be improved in future by guiding the traveling block between some kind of guardrails or walls. The loss of energy during the impact of a block in the launch test is not considered as decisive in relation to the above-mentioned disadvantage of purely translational tests. The final aim has to be to test blocks in full consideration of their angular velocity.

- The guideline shall cover barriers with **limit energy dissipation capacities** from 100 to more than 2.500 kJ.

- There will be no **total energy** given. The producer has to decide on the energies he wants his system to be tested. Three different energy levels and their sequence are under discussion:

  1. **Zero Maintenance Level** (ZML) is characterized by the highest translational energy a barrier can dissipate without any plastic deformation.

  2. **Service Energy Level** (SEL) is defined as the maximum translational energy a barrier can repeatedly dissipate under the condition that the rock is stopped.

  3. **Maximum Energy Level** (MEL) is the highest translational energy a barrier can dissipate under the conditions that the rock is stopped (the system might loose its ability to stop another block with the same or an even considerably lower energy).

Independent of the energy levels the tests will start with small blocks in the order of magnitude of the primary mesh size or even below proving that the system is able to stop these, too.

One of the major questions being still under discussion is the definition of targets. An actual proposition by the delegates of Austria, France and Italy is shown by figure 2.

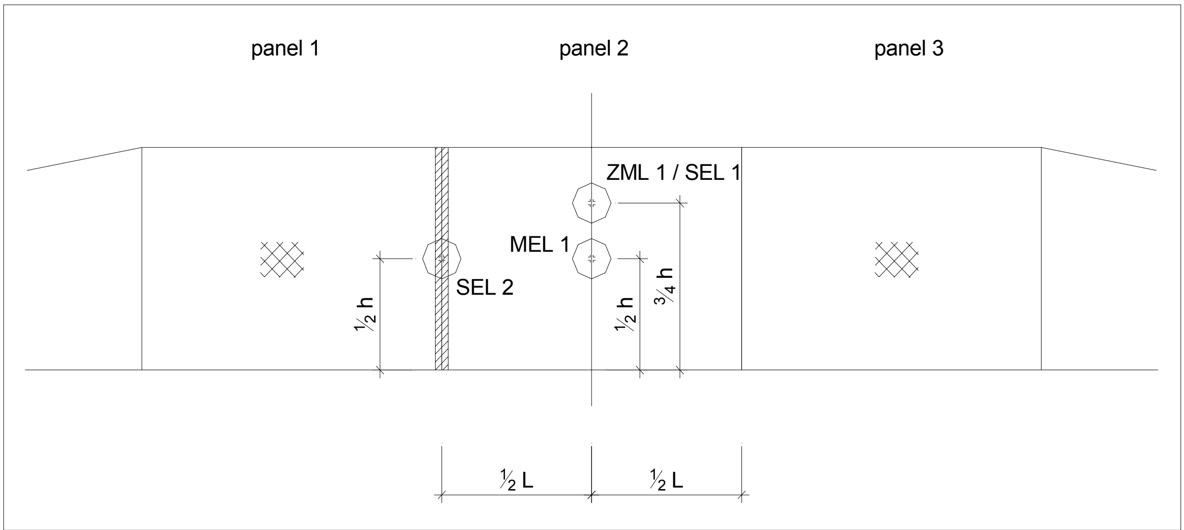

Fig. 2: Targets according to an actual proposition of the Austrian, French and Italian delegates.

The majority of the working group favors one test only of each kind with the same characteristics, i.e. the same energy under the same angle of impact and at the same point of the net. The resulting total number of tests would be four.

Assessment of the actual state: The actual proposal has some evident shortcomings.

- The **number of tests** is much too small for any statistical evidence.

- The proposed **targets** are not representative for the behavior of the system. They cannot reveal weak areas.

- The targets for the ZML and for the SEL 1 are identical whereas most of the area of the net is not tested.

- The **definitions** are qualitative. What does “no plastic deformation” mean in practice? Only small energies will be dissipated by pure elastic or better reversible behavior. Reversible behavior includes not only linear (following HOOKE’s law) and non- linear elongation, but also friction due to relative displacement under normal stress. If one has ever seen an impact on a modern ring net, there is a lot of reversible displacement between the rings themselves and between the outer rows of rings and the suspension cables. In the immediate impact area, rings may become deformed permanently to squares or hexagons, depending on the number of neighbors, long before the brakes are activated. These local plastic deformations do not affect the remaining limit energy dissipation as long as no ring or cable brakes. By the way, the probability of a subsequent impact on just the same point is very low. Additionally ropes may be plastically stretched to an extent being hardly measured and not being visually detected. The definitions must therefore be based on clearly observable phenomena; “gray zones” will generate clearance for the assessment of test results and lead to disputes. The three energy levels have to be correlated to the frequency of rockfall resp. to the return period and to the resulting design considerations to give them a practical relevance.

Alternative approach: These requirements lead to the following suggestions.

- ZML represents the “daily events” with a return period up to one year. These events shall not cause any maintenance cost. The necessary removal of accumulated rock is not considered, because it does not depend on the barrier type.

- SEL represents the events with a return period of less than or equal to10 years. To accept maintenance is reasonable from economical reasons. Otherwise, the system would have to be over dimensioned. Because of that return period, being short in relation to the proposed lifetime of the structure, the barrier must be able to withstand repeated impacts with the SEL energy.

- MEL stands for events with return periods of less than or equal to 100 years. The system has to stop the block, the probability of a second one following in between the usual inspection period of less than 1 year, is very low. Thus, it is acceptable that the system looses its ability to catch subsequent blocks. For real applications the MEL might be combined with warning devices, indicating that certain important cables are broken.

Of course, it is up to the employer to decide for other return periods a design having to be based on. The suggested definitions are as follows:

1. **Zero Maintenance Level** (ZML) is characterized by the total energy a barrier can dissipate without any broken parts, gaps in the net, and activation of brake elements. Visible plastic deformation is allowed, if it is restricted to the immediate contact area between the block and the net. In case of doubt, this area is assumed to half the surface area of the block.

2. **Service Energy Level** (SEL) is defined as the total energy a barrier can dissipate in three subsequent tests at the same point of impact and without any repairs between the impacts under the condition that the rocks are stopped. Gaps are not tolerable; the remaining minimum height must be at least 2/3 of the original minimum height.

   The restriction to thwo tests is necessary, because the SEL will be considerably higher than the ZML and will activate the brake elements. The brake elements have a defined maximum displacement. If this maximum is reached, the effect of the brakes is exhausted. SEL will include in practice the replacement of activated brakes. Three tests present a reasonable safety margin allowing two subsequent impacts between two inspections without creating a danger for the installation to be protected. Gaps would affect the protective effect of the barrier, as would a further reduction of height. Of course, one could discuss about a restriction to two tests and a remaining height of 50 %. To this author's opinion, it is the intention of these tests to come to safe designs and not to world records in energy dissipation. The suggested numbers follow this aim.

3. **Maximum Energy Level** (MEL) is the highest total energy a barrier can dissipate under the condition that the rock is stopped The system might have lost its ability to stop another block with the same or an even considerably lower energy. Gaps and broken parts are allowed. In practice, the system would have to be repaired or even replaced. With this tests not only the limit energy dissipation shall be determined, but the maximum elongation, too. There is a small uncertainty in the real maximum, because of the requirement the block being stopped. If the energy is bigger than that value and the net fails, the elongation might be greater.

All visible or measured changes after impact have to be described in a test report, being part of the certification.

- The proposed targets are shown in figure 3. Hits on retaining cables and posts are considered a must in spite of the facts that posts require a high accuracy of hitting and bearing the possibility of damaging the block. Because random factors shall be excluded, at least two tests are necessary to come to reliable results; three tests would be desirable. Two tests may be a compromise to be accepted from financial reasons. The more favorable test shall be neglected.

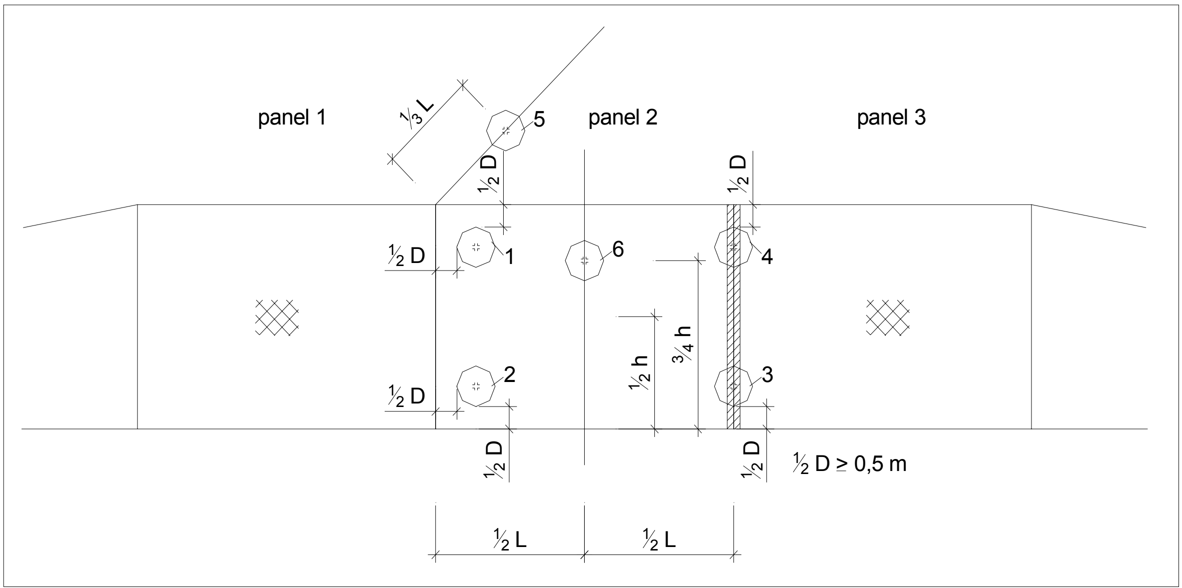

Fig. 3: Proposed targets according to this author's suggestion

- As already discussed above a comparison between different systems without getting the limit energy dissipation makes no sense. It is indispensable therefore to concentrate on the weak points of a system. The strong ones are of no practical use in design. It will not be necessary to test the weakest point of the system by the ZML, assuming that the weakest point is either independent of the applied energy or that its identification is more important for the SEL and for the MEL. This assumption reduces the number of tests without having a decisive influence on safety.

To the opinion of this author, the sequence of tests must be as follows.

1. SEL tests in the left lower and the left upper corner of the panel (or in the right corners, but anyway in the corners on the same side). Additional tests on the foot and on the top of a post as well as in the downhill third point of a retaining rope, as far as the system allows for such hits. This are 2 x 5 = 10 tests. To reduce cost of testing the producer may determine the sequence of the above mentioned tests, for example to start with the most critical one and to interrupt the tests, if this one should fail.

2. ZML tests in the area proven as the weakest according to the previous test series. This requires two tests.

3. MEL tests in the area proven as the weakest in the SEL tests. This requires two tests. Additional two tests are necessary in the center of the barrier respectively in the area of the maximum flexibility. This requires another two tests respectively a total of 2 x 2 = 4 tests.

The total of tests is 16, if the tests series is not interrupted because a test did not fulfill the requirements.

If the system is over dimensioned in relation to the energy levels, the producer wants to have it tested, it might be difficult to identify the weakest point of the structure. In this case, the test engineer has to select the targets for ZML and MEL according to his experience with similar systems and on the base of previous tests of the producer. He has to explain the reasons for his decision as part of the certification.

In the case of a system having the posts and the retaining ropes on the downhill side of the net, SEL tests can be reduced to the above-defined corners of the middle panel (near the lower and the upper suspension rope), the zone with the highest flexibility and to the area, where a post supports the net. If the neat between two panels is apart from the posts, 2 x 4 = 8 tests are necessary, otherwise only 2 x 3 = 6. If no weak point could be identified during these tests, the test engineer shall decide on the targets for the ZML and MEL tests according to his experience and on the base of previous tests executed by the producer. He has to explain the reasons for his decision as part of the certification.

- **Measuring program:** Because the foundation conditions generally may be different from those of the test site and the forces transferred to the ground are dependent on the system a minimum approach is to measure the forces acting in the retaining ropes and in the foundation of the posts. The producer is free to order additional measurements, for example of the forces acting in the suspension ropes or / and in the posts.

- **Repair of damages** allowed: There is no repair of damages allowed during a test series with the same characteristics. Between the series it is up to the producer whether he repairs or replaces his system. If a system fails, the test has to be repeated.

- **Rock removal** after impact or accumulation allowed: The block is removed after each test. The effect of accumulation is not tested.

- **Tolerances:** Of course there is a need to accept tolerances, for example in measuring the weight of the block, its velocity and many geometrical data. These tolerances depend on the accuracy of usual measuring procedures in construction and range between 3 and 5 % of the required value.

- **Institutions** to carry out the tests and give the certifications: There will be a list established by national authorities with those institutions to certify rockfall barriers according to the above described regulations.

Conclusions

There is a need for harmonized tests not only in Europe, but also worldwide. A close international cooperation especially with our American colleges would be very desirable. The decisive points being still open are the basic tasks of the tests, the number of tests, the targets and the definition of the behavior under these different energy levels.

From a scientific point of view, there are some key points to be considered:

- The number of tests with the characteristics, i.e. the same hit area and the same energy must be at least 2, a statistically relevant number of at least 3 would be desirable.
- The most or the more favorable tests have to be neglected.
- The tests must give all data, the limit total energy dissipation capacity under different practically relevant energy levels especially, being necessary to select systems for a safe design.
- The tests must reveal the weak points of a system. Thus, all critical areas and parts have to be tested. It would be not acceptable having systems granted a ETA respectively a certification, if they were not tested under the most unfavorable conditions, for example if it is not tested that the system will not collapse under a hit on one of the retaining cables or a post.
- Economic reasons may be considered in defining the number of tests, but their influence must stay secondary according to the rule: don't compromise with safety.

Because the development of rockfall mitigation systems is rapid, the knowledge on the behavior of rockfall barriers is not developed to a general accepted state of the art, and a lot of decisive questions are still scientifically unsolved, the intended guidelines will represent a first step. An advanced version will be needed some years later, based on the experiences of the beginning tests on the Swiss test installation at Walenstadt, too. In spite of that perspective, it is urgent to finish this first approach to channel the actual development and to come to a defined safety standard, even if some shortcomings will remain.

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