THE DEVELOPMENT OF UIAA SAFETY COMMISSION STANDARDS FOR AVALANCHE RESCUE EQUIPMENT

Manuel Genswein [1, 2, 4, ☯, *], Davide Rogora [3, ☯], Vittorio Bedogni [3, 4], Dave Custer [4, 5]

(1) International Climbing and Mountaineering Federation UIAA
(2) MountainSafety.info
(3) Research Center for Equipment and Techniques, Italian Alpine Club (CSMT of CAI)
(4) UIAA Safety Commission (SafeCom)
(5) Experimental Study Group, Massachusetts Institute of Technology MIT
(☯) These authors contributed equally to this work

In 2013, the UIAA Safety Commission (SafeCom) undertook the development of worldwide minimum standards for avalanche probes and shovels. Previously, formal requirements for avalanche shovels and probes only existed for participation in ISMF ski touring races, mainly with the aim to ensure equal and fair racing conditions for all athletes. While not legally binding, UIAA SafeCom standards represent a self-regulatory approach for the only worldwide, industry standard for mountain safety equipment. Initially, the avalanche rescue standards project focused on the now published UIAA 156 standard for avalanche rescue shovels; the final standard proposal on probes is expected to be ready for final voting by spring 2019. UIAA federations as well as manufacturers of the respective products have voting rights within SafeCom.

During both shovel and probe standard development projects, a laboratory and field reference database has been built up to correlate lab test results of generic product characteristics with failure modes in the field. For the avalanche shovel standard, laboratory testing has been carried out in the research lab of the Italian Alpine Club in Padova. The reference database included eight tests criteria: blade compression, direct and reverse cantilever bending, positive and negative three-points bending, interface tests in compression and extension as well as blade edge strength. The practical field tests took place in multiple countries including users from Poland, Slovakia, France, Italy and Switzerland. Following the approach of MountainSafety.info, companion and organized rescuers from the user groups of alpine clubs (UIAA), mountain guides (IFMGA), mountain leaders (UIMLA), military mountaineering schools (IAMMS) and organized rescuers (ICAR) where included in the test series. 324 individual excavations leading to 45 laboratory cross-checked excavations per reference database test article were performed. Morphologic, safety relevant requirements such as blade surface and total length dimensions were derived from this dataset. The laboratory and field data showed good correlation, and three easily measurable, quantitative lab values were recognized to be able to identify the safety critical thresholds. Thus, the aim of an economically viable, technically feasible, reproducible test procedure has been reached. After a minor revision in spring 2018, UIAA Safety Label products are expected to be available on the market for the 2018/2019 winter season.

Keywords: Avalanche Rescue, Avalanche Rescue Equipment, Safety Standards

* Corresponding authors address:
Manuel Genswein,
General Willestrasse 375,
8706 Meilen, Switzerland;
E-Mail: Manuel@Genswein.com

1. INTRODUCTION

The UIAA Safety Commission (SafeCom) and thus the development of safety standards started in 1960. Testing of ropes and other climbing related equipment was the focus of Safecom for decades. Concerning avalanche safety and rescue products, avalanche transceivers triggered an early need for regulation due to their transmit function and frequency use [1]. More recently, mandatory legal standards have been set in place for avalanche airbag systems. However, only in 2017 UIAA SafeCom released the first standard on avalanche shovels [2], in despite of fact that the survival chances of a buried subject heavily depend on effective pinpointing and fast excavation. An additional UIAA SafeCom standard concerning avalanche probes is expected to be released in 2019.

2. METHODS

2.1 *Failure modes*

Potential failure modes taken into consideration originate from a field study population that has been built up since 2007 as well as expert know.

2.2 *Reference database*

In order to properly understand the generic characteristics of avalanche rescue shovels, a reference database containing 23 different test articles from eight different OEMs has been built up. The 23 test articles were selected with the focus of adequate coverage of the different construction styles, materials, blade sizes, shaft lengths and handle design available on the market. The reference database included for all test articles a similar amount of laboratory data and field test data. As the manufactures represented in UIAA SafeCom have already expressed in the very early stage of the project that lengthy and costly test procedures shall be avoided, endurance testing with a high number of repetitions as well as testing in a conditioned environment was abandoned.

The field test component of the reference database therefore had three important goals to fulfil:

- Verify if all the relevant failure modes considered for the planning of the lab tests were properly recognized.
- Evaluation of the safety critical threshold which distinguishes acceptable products from product which do not fulfil the minimum expectations.
- Inclusion of endurance testing and environment related parameters which are not reproduced in the laboratory testing.

2.3 *Laboratory testing*

Eight different laboratory tests where evaluated to recognize the different reported failure modes:

- Cantilever bending type 1 and type 2 to detect a blade flexural and/or crippling collapse
- Three point bending type 1 and type 2 to detect a shaft or blade assembly flexural collapse
- Interface test in extension and compression to detect failures of the locking mechanisms
- Penetration test to detect crippling or collapse of edges and determine cutting characteristics
- Compression test to detect a blade column collapse

All laboratory test were carried out in the laboratory of the Italian Alpine Club (CAI) in Padova operated by CAI's Research Center for Equipment and Techniques.

To perform the cantilever bending type 1 and 2 testing, test article specific resin clamps were casted to suite each shovels profiles. As such, the clamping of the test article in the laboratory perfectly reproduced the real on-snow situation where the blade is completely surrounded by snow. The blades where clamped at 50% of their total blade height in a polyester type material.

In order to exclude non-linearity, in particular at very low loads due to settlement of the shovel connector parts, clearance recovery and the settlement of the test setup itself, the industry standard secondary modulus was applied. As the method was considered as over-engineered by the outdoor industry, the process had later to be lower to adapt to the capabilities of the outdoor industry. In the simplified and final procedure, the load is increased to the threshold given by the standard and then released to the zero deflection reference point. At this point the residual deformation is determined by the displacement.

To take in to account the effects of brittle phenomena of plastics and composite materials, preconditioning of test articles has been evaluated, but had to be abandoned as the rewarming rates have proven to be by far too high taking into account the required testing duration at reasonable loading speeds. Thus, UIAA SafeCom standard 156 includes requirements for the brittle transition temperature tb [3] and glass transition temperature tg [4] to exclude brittle behaviour of the materials within the operation temperature (tb < -20°C < tg).

2.4 Field testing

The objective of the field tests was to record the stress added to the test articles in a wide range of application cases and user groups. The practical field tests took place in Poland, Slovakia, France, Italy and Switzerland, including companion and organized rescuers from the user groups of alpine clubs (UIAA), mountain guides (IFMGA), mountain leaders (UIMLA), military mountaineering schools (IAMMS) and organized rescuers (ICAR). All participants were instructed in the proper application of the snow conveyor belt excavation strategy. Whereas some inevitable peak force exposure due undesired motion of the rescue was accepted, any other kind of incompliant application of the excavation technique leading to excessive stress of the test article was immediately stopped by test supervisors. The excavation technique was applied in teams of 3 rescuers. 324 individual excavations leading to 45 laboratory cross-checked excavations per referenced database test article were performed.

The hardness of the snow pack in the test sites was in average equal to a "four finders" rating in a snow profile. Thus clearly chosen to simulate a companion rescue situation where the rescue effort starts immediately after the accident has come to stop and before a post-accident refreezing and sintering effect may lead to very considerable increase of debris hardness. In the case where snow pack hardness was clearly weaker or higher than "four fingers", snow pack hardness correction factors where applied to prevent an undesired bias to rescue performance relevant values such as the "liters per minute per rescuer" performance value.

In order to measure the influence of total shovel length, blade size and shovel blade configuration (hoe or normal) to the excavation performance, every test team had to perform multiple test runs using different combinations of test articles. The hoe configuration was applied by 1/3 of the workforce at the open end of the conveyor belt, where the it was most likely to be able to have an advantage in using the tool in this configuration.

After each test cycle, the test article has been visually inspected for damage and finding concerning morphologic requirements were protocolled. Test cycles to analyze the influence of total shovel length to rescue performance, were carried out with equal blade surface. Equally, the test cycles to analyze the influence of the blade surface to rescue performance, were carried out with equal total shovel length.

Each test team consisting of tree rescuers had to perform at least one complete dataset of eight test cycles: three datasets for total shovel length, three data sets for blade surface and two datasets for the hoe function. This procedure allowed to calculate the increase or decrease of excavation performance in percent within a full dataset of blade surface, shovel length and hoe function data.

In order to avoid bias by fatigue of the test personnel, mandatory rest periods during which the participants were taught avalanche search and rescue strategies were intro used.

3. RESULTS AND DISCUSSION

While an as comprehensive inclusion of tests and potential influence variables as possible was indispensable at the beginning of the standard development, identification of the most relevant tests to distinguish acceptable products from products which were not considered to fulfill the minimum requirement in rescue efficiency and safety margin was one of the key component of the advanced development phase. Three point bending type 1 and type 2 results did not show to add an advantage in the reliability to predict if a product is suitable or not in addition to the cantilever bending type 1 and type 2 tests. Interface testing in extension has been identified to be sufficient to detect the relevant interface related failure modes, allowing to omit interface testing in compression mode to reduce testing time and make certification more economic for manufacturers. It is important to add that all conclusions had to made based on the characteristics of the test articles in the reference database. As with every product standard, the ongoing and desirable innovation process of the industry demands standards to be continuously updated.

The compression test to detect a blade column collapse has been proposed in a manner where the force was slowly increased as well as in a second manner simulating a shock load. Whereas the first alternative has not shown to add a higher sensitivity in edge collapse prediction than the cantilever bending at 50% of the blade length, the shock load alternative had to be abandoned as it was considered as an invalid test procedure to produce reliable, reproducible results. The penetration test to detect crippling of edges has equally been abandoned with the same rationale as the blade column compression test with a slow increase of the applied force.

The field tests have shown that the test articles which are by the current SafeCom 156 standard considered as insufficient show very fast signs of irreversible deformation, very soon leading to complete failure of the product. One third of the products not fulfilling the requirement to remain within 5% of permanent deformation after being exposed to 300Nm of cantilever bending typically failed already in the second excavation trial, two thirds of these products failed during the seventh excavation trial. The mechanically weakest test articles in the reference set showed for 1/3 full failure at during the second excavation, 2/3 during the third excavation and 100% failure during the fourth excavation. While these products are designed for customers looking for very lightweight or low cost products, the dramatic reduction of rescue efficiency shows the necessity for neutral advice of the customer by a safety label. SafeCom has decided at the very beginning of the standard development that a product for companion or professional rescue shall be able to accept the required training cycles before being used in a real rescue case. Thus a concept of a "one time use" product for the benefit of lower costs and weight was immediately abandoned. ISMF may accept in this context lower thresholds as their mandatory safety precautions and organized rescue preparedness for official races as well as the immediate availability of multiple athletes at the rescue scene can tolerate considerably lower longevity of an avalanche rescue shovel still allowing fast rescue times taking all components of the system into account.

The total length of the shovel influences rescue excavation performance. Compared to the shortest test article with a total length of 64.5cm, shovels with a total length of 78cm provided a gain of +15% in excavation performance for companion and 21% for organized rescue. For very long shovels with a total lengths of 87.5cm, the benefit was reduced to 8% for companion rescue and only provided another +6% advantage to a total of 27% for organized rescue. Thus already for the total length of the product, there is evidence for an *optimal* value for morphologic criteria. Performance will decrease on both ends of the optimum. Concerning blade size, shovels with a surface of 577cm2 showed an increase of excavation performance of +16% for companion and +15% for organized rescue compared to the smallest tested surface of 538cm2. A further increase to 673cm2 only provided a minor increase of performance of +1% for organized rescue, whereas companion rescuers suffered a net decrease of -5% compared to the 538cm2 products. The in average lower physical preparedness in companion rescue as well as the higher percentage of female participants within the companion rescue collective leads to an early reduction of performance when the product itself is heavy and built for large scoop volumes requiring more force for each movement.

Even though the snow pack hardness was very moderate, optimized to simulate a companion rescue situation, the hoe function was not able to increase the "liters per minute per rescuer" performance value in a positive manner. Only within the group of organized rescuers it was possible to keep the performance at the same level (neither loss nor gain) when applying the hoe function. Within the group of companion rescue, the rescue performance was decreased by 15% when the hoe function was applied at the open end of the snow conveyor belt.

Increase or decrease of excavation performance in percent for blade surface, total shovel length and hoe function was first calculated within each complete dataset recorded by a team of tree rescuers. In a second step, the overall increase or decrease of excavation performance was then calculated based on the *relative* gain or loss values of each team. This approach can tolerate variability in physical performance between test teams and variability between snow conditions on different test days and on different test sites. Absolute values for excavation performance are unsuitable as this approach would require equal participants performance and equal snow conditions for the entire duration of the test series.

4. CONCLUSIONS AND FUTURE OUTLOOK

The laboratory and field data showed good correlation, and three easily measurable, quantitative lab values were recognized to be able to identify the safety critical thresholds. Thus, the aim of an economically viable, technically feasible, reproducible test procedure has been reached. As for the laboratory testing, cantilever bending type 1 and type 2 as well as the interface test in extension were identified to be sufficient to detect the test articles with acceptable characteristics in the reference set. In the cantilever bending tests, products must remain within a max. +5% residual reformation threshold (relative to the total length of the shovel) after being exposed to a 300 Nm bending moment. In the axial pull test procedure, testing the interfaces in extension, products must withstand 1000 N without any rupturing of parts nor any other sort of material separation.

In order to fulfill the minimum performance expectations of the UIAA SafeCom 156 standard, a shovel needs to have a blade surface equal to or exceeding 500cm2 and a total shovel lengths equal to or exceeding 75cm. Average trained companion rescuers show a better rescue performance with a medium size blade surface of approx. 580cm2 compared to shovels with large blades. For most companion and organized rescuers, shoveling at a higher pace with a medium blade size shovel is much more likely to increase excavation performance compared to increasing the blade size. Only for physically very strong individuals, a large blade size results in an increase of excavation performance, whereas the majority suffers a loss of performance due to early fatigue.

In contrast to manufacturer-funded studies in artificial environments and a single rescuer configuration, our real world on-snow testing in a small group configuration shows that the hoe function lowers rescue performance (-15%) in avalanche rescue. The hoe function therefore only might makes sense for very specific, non-avalanche related rescue scenarios such as tree well accidents, where large masses of soft snow need to be moved from the lower end of the tree. Whereas this finding is not reflected in the UIAA SafeCom standard 156, it is an important fact to be communicated in avalanche rescue training.
Since the evaluation of test articles for the reference database and testing for the current UIAA SafeCom 156 standard, manufacturers have continued product development.

The UIAA workgroup was made aware of new products with a particular choice of materials selected for the shaft and the blade, which was not part of the original reference database. Development of new standards and updating of existing standard is the key task of UIAA SafeCom in collaboration with federation and industry representatives. This continuous process offers an optimal balance between warranting minimal safety standards and allowing innovation by adaptation of existing standards to new product characteristics. As a consequence of this continuous adaptation process, the workgroup is currently investigating two new test articles and might propose to the commission in the future an amendment of the standard, if required.

Concerning the future standard of avalanche probes, the reference database has been built up and is completed for the laboratory component. However it has been identified that additional field test data needs to be collected during the 2018/2019 season. The standard is supposed to be ready for voting during the 2019 annual meeting of UIAA SafeCom.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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