Field tests of some new avalanche rescue devices

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[†] Frank Tschirky died shortly after the tests had been finished on April, 25, 2001 during a trekking in Nepal. From the beginning, Frank has guided the work on avalanche airbags at the Swiss Federal Institute of Snow and Avalanche research, Davos (SFISAR) with large personal effort. He managed all the accident statistics and contributed a lot from his large personal experience to the further development of ideas.

Summary

The effectiveness of different kinds of avalanche rescue devices was tested in the field during the winter of 2000/2001. Thirteen test dummies equipped with and without avalanche airbags were placed in an avalanche slope, which was then artificially released. The burial depth of the dummies was recorded. Additionally, the loads on the cervical vertebrae were measured by a dummy equipped with sensors provided by a car manufacturer. The tests confirmed, that wearing an avalanche airbag generally decreases the burial depth of avalanche victims. The inflated avalanche airbags were always visible on the surface of the avalanche deposits, and therefore can be regarded as good markers which help to decrease burial time and thereby increasing survival chances of avalanche victims. The loads acting on the cervical vertebrae of victims during avalanche flow appear to be considerable, such that fatal injuries seem possible. Additional research is needed to estimate the effect of the different kinds of avalanche airbags on the amount of mechanical load. A decrease of load acting on the cervical vertebrae by wearing a polo-neck shaped airbag could not be proved due to the limited number of results.

Keywords: avalanche accident, avalanche rescue, avalanche airbag, avalanche burial

1 Introduction

The ABS Avalanche Airbag is the first avalanche rescue device, whose primary claim is not the facilitation and acceleration of rescue, but which is supposed to avoid the burial of the victim underneath the snow altogether. Although the balloon can act as localisation aid, it should always be complemented by an avalanche beacon (“tracker search device”). Tracker search devices operate on the emitter-receiver principle and are not the subject of the investigation described in this document (1).

After field trials on the effectiveness of the ABS Mono Airbag undertaken by the SLF in the winter of 1994/95, research was mainly limited to the recording and analysis of accidents involving people wearing airbags (2). Theoretical considerations on the effectiveness of the avalanche airbag pointed towards the principle of inverse segregation in granular flows being instrumental.

In all known cases involving individuals equipped with the avalanche airbag, there was only one fatal burial out of a total of 40 people, who were swept away.

The avalanche airbags have been on the market since 1985 in form of the "Mono Airbag". The emergence of the dual ABS Airbag system, the prototype of the "Avagear" rescue vest and the K2 "Avalanche Ball" represent new development in the rescue devices sector over recent years. The principle of operation of these new devices is also based on the phenomenon of inverse segregation in granular flows. The K2 Avalanche Ball primarily acts as a non-electronic detection device.

These developments raise the question whether and to what extent these new devices fulfil their respective objectives of avoiding the burial underneath an avalanche or the facilitation of detection and recovery of an avalanche victim compared to the Mono Airbag system. Furthermore the problem of stresses in the human body exposed to an avalanche is an important one: It is not clear how many people die of mechanical injuries in avalanches (3). Therefore it was the aim of the field trials in the winter of 2000/2001 to conduct a functional test with the newly developed devices and to measure the forces acting on an avalanche victim with the help of a crash test dummy equipped with forece measurement devices, as used in the automobile industry.

2 State of knowledge

2.1 The operational principle of the Avalanche Airbag

The effect of "inverse segregation" in granular flows, which forms the basis for the Avalanche Airbags operational functionality, was investigated by KERN with the help of theoretical and numerical models. An explanation for the effectiveness of the ABS System is achieved by interpreting the flowing avalanche as flowing granular medium, which is composed of differently sized particles. Under the influence of gravity granular flows tend to segregate in way that leads to bigger particles being found at the surface and smaller particles finding their way to the lower layers of the medium. This separation process is known as "inverse segregation". The process of inverse segregation is primarily dependant on the relative sizes of the granulate particles. The Avalanche Airbag renders the skier , who by himself already represents quit a large particle amongst the avalanche granulate, an even larger particles, which is subjected to the separation effect to an even greater extent.

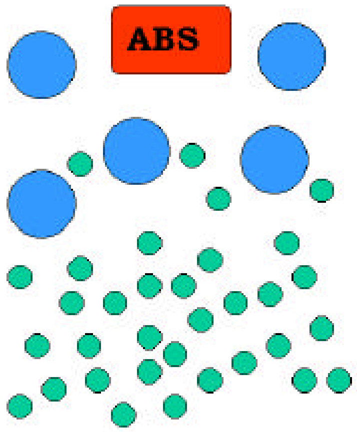

Fig.1: Schematic of inverse segregation

2.2 Field trials in the winter of 1994/95

In the winter of 1994/95 the first tests were conducted on the Mono Airbag manufactured by ABS Peter Aschauer GMbH from Gräfelfing in Germany (TSCHIRKY et al. 1995). These tests showed that the balloon was not capable of consistently preventing complete burial, but there was large probability of the balloon being visible at the surface, thus representing a very effective method of locating and rescuing avalanche victims. Since then no further large scale tests have been undertaken.

2.3 Known avalanche accidents with Avalanche Airbags

In the winters of the years spanning 1990/91 until 1999/2000 a total of 29 avalanche accidents, in which people wearing an Airbag were swept away, were reported to the SLF (TSCHIRKY 2000). 35 of a total of 44 people involved in these accidents were able to successfully release the avalanche balloon in time. In three further cases technical the device suffered technical failure. These figures demonstrate clearly that the manual release of the Airbag by the user represents a weakness. The release has to be practised, so that it is handled confidently in extreme stress situations.

The 9 people, who were caught by the avalanche with their Airbag uninflated, survived the event without any injuries or only slightly injured. Of the 35 people, who had released the Airbag in time, 5 were completely, 15 partially and 16 not buried at all. "Complete buried " is defined a condition were at least the head and thorax are buried, so that a potentially life-threatening situation is given. In the case of the people, who were reported completely buried, the balloons were visible at the surface in all except one case, so that fast location and rescue was possible. In one case however, where the avalanche was unusually large the victim including his inflated Airbag was buried by a secondary avalanche and could only be salvaged dead. The risk of being completely buried even with an inflated Airbag when situated in hollows or with avalanche release occurring at the foot of the slope, has been highlighted before (TSCHIRKY/SCHWEIZER, 1997).

Investigation to date have shown that the Avalanche Airbag is a useful addition to the current equipment carried by off-piste skiers. It however cannot ever provide complete protection from the effects of an avalanche release.

A comparison with the larger data set of avalanche accidents (without airbag) from the region Davos, Switzerland (SCHWEIZER/LUETSCHG; 2001), which should be similarly complete, shows that the fraction of people suffering complete burials is not significantly different for both data sets (p=0.07). Contrary the to the users of ABS Airbags however buried non-users are often not visible in the avalanche that has come to a stop. Comparing the low fatality rate of merely 20% of people using the AS Airbag, who are completely buried, with that of the reference data set also yields no significant differences, although the low number of incidences (N=5) strictly speaking does not allow for statistically conclusive statements.

3 Characteristics of the tested devices

3.1 ABS Mono Airbag

The ABS-Mono Airbag has been commercially available since 1985 and therefore is the first commercial avalanche rescue device, whose action is based on the principle of inverse segregation. The system compromises a 150l balloon, which is housed in a rucksack, released with a pull chord and inflated within 2-3 seconds by means of a valve system fed by air from a pressure cartridge and the environment.

3.2 ABS Double Airbag

The balloon volume is split into two balloons with 75l each in the case of the ABS Double Airbag ("dual system"). The two balloons are housed in side pockets (one each side) of the rucksack (Fig.2). The release is no longer initiated via pull chord as with the Mono Airbag, but is achieved by the means of a pyrotechnic charge. A charge located in a handle produces a shock wave, which propagates up a pressure hose to the pressure cartridge and opens the latter with a metal pin. The advantage of the dual system lies in the fact that it can be stowed away in a much smaller volume allowing more luggage space. Moreover the rucksack is more comfortable to wear in this configuration.

Fig. 2 : Test Dummy with Double Airbag. Major experiment at Pischa-Wäng, 16. März 2001

3.3 „Avagear“-Rescue Vest

The "Avagear" Rescue Vest was developed in the USA and currently only exists in form of a prototype. The system consists of a 90l balloon, which forms itself around the neck and as the ABS Airbag is inflated from a pressure cartridge. The release mechanism utilises a pull chord. The prototype that was tested in March 2001, did not have functioning inflation mechanism, so that the balloon had to be manually inflated before the experiment using an air cylinder.

Fig.3 Measurement dummy with Avagear rescue vest

The developers are hoping that the encasing of the head by the balloon will produce fewer incidences of buried heads than for the ABS Airbag or at least promote the formation of a breathing cavity. In addition the shape is meant to reduce the forces acting on the throat and neck region. The tests were intended to show in how far these claims could be verified.
In the main experiment a dummy that was fitted with force and angular moment sensors as well as an "Avagear" rescue vest was used.

3.4 K2-"Avalanche Ball"

The K2-"Avalanche Ball" is a development of the traditional avalanche string concept and therefore significantly differs from the other rescue devices that were tested. The lampion-shaped ball with a diameter of approximately 60 cm is stored in a system bag in folded form. The pulling of a pull chord results in the opening of the system bag, thus releasing the ball, which is unfolded within fractions of a second by the means of a spring mechanism. The ball is attached to a 6 m piece of rope , which is fastened to a waist belt at the other end. In the event of an avalanche the ball has the tendency to stay at the surface of the snow due to the inverse segregation effect. The combination of its visibility and the attached string is supposed to enable an easy visual location of the buried person. For the main experiment, two dummies were equipped with the avalanche ball, in order to tests their effectiveness in the location of buried avalanche victims.

4 Field Trials

The comparative functional tests of the above mentioned avalanche rescue devices were conducted as part of a major field trial in the Pischa region near Davos on the 16 March 2001. In addition two more experiments were undertaken with the instrumented dummy in order to quantify the stresses that a human caught up in an avalanche is subjected to.

4.1 Equipment: Test Dummies and the Instrumented Dummy

The major experiment included the use of 13 conventional dummies. 12 of these were US-manufactured dummies used for the training of rescue teams (CMC Rescue Manikin, compare Fig. 2). They posses movable limbs and weigh 85 kg.

The 13th dummy was a humanoid instrumented Hybrid-III dummy, as is primarily used in the automobile industries and accident research. The Hybrid-III dummy was tested in a seated position and weighs 75 kg. Sensors to measure deformation are situated in the thorax and 6 further sensors are located in the cervical vertebrae region in order to record the shear forces and turning moments acting in all three dimensions. The data is recorded on a mobile Campbell CRX-10 data logger that was configured by the SLF and has resolution characteristics particularly suited to the dynamic load changes in the vertebrae area caused by the avalanche. The data logger was attached to the back of the Dummy. To avoid water ingress into the measurement instrumentation the dummy was dressed in a Gore-Tex Overall.

4.2 Preliminary experiments on 1 March 2001

After the comprehensive adaptation of the data logger to the sensor outputs from the instrumented dummies and the calibration in the laboratory the Dummy was flown by helicopter to the Vereina Valley near Piz Fless on 1 March 2001. The avalanche initiated by means of explosives was too small to entrain the dummy. In a second experiments the dummy was also positioned on a couloir with north-west exposure close to the Plattenhörner. A small flowing avalanche, which dragged the dummy 100m, was released using two explosive charges. The dummy was turned over several times by the avalanche and eventually came to rest on the avalanche deposits in a semi-buried state. The recorded force and turning moment diagrams were of similar shape to Figs. 8 & 9, where the maximum recorded shear force amounted to 500 N and the maximum turning moment reached 45 Nm.

4.3 The Major Experiment on 16 March 2001

For the major experiment on 16 March 2001 a total of 13 dummies was positioned at the positions indicated in Figs. 4 and 5 on the experimental slope "Wäng" in the ski region Pischa. Four of the 13 dummies were equipped with inflated ABS airbags, 3 were wearing the Avagear rescue vest and 2 had an Avalanche Ball. 4 dummies were not equipped with any particular rescue device. All dummies were however equipped with an electronic location device (LVS), so that they could be located in case of complete burial. The dummies were numbered as outlined in Table 1, so as to allow identification after the avalanche had taken place.

A medium-sized avalanche was released by means of 3 explosive charges, which were attached to posts approximately 50 metres above the dummies and were connected by a fuse (Zündschnur). It had a fracture height (Anrissmächtigkeit) of 20-40 cm, a width of approximately 75 m and a length of 400 m (compare Fig. 6). All dummies were swept away and were deposited as shown in Fig. 5. The avalanche that was released is representative in size of a snow slab avalanche typically initiated by skiers (SCHWEITZER/LUETSCHG 2001). The release depth, the width and the topography of the outrun however were such that complete burial of all dummies was unlikely to occur. The following results are therefore to be viewed with this fact in mind. As a result any remarks made concerning the burial depth are of a relative nature. The deposition (compare Fig. 5) reached a height of 0.5 m in the flatter region (deposition location 1) and about 2.5 m in the area of the main deposition (deposition location 2). The positions and the burial depth of the dummies were recorded after the avalanche had come to a halt. The reference point for the burial depth was taken to be the face of the dummy. One of the dual airbags was damaged in the avalanche: one of the two 75 l balloons was torn away off the rucksack.

8 of the 12 CMC- dummies suffered detachment of the lower limbs at the knee-joint due to the high mechanical loads experienced during the avalanche. As the manufacturer quotes the axial strength of the knee-joint as 20 kN, it is obvious that the loads on the dummies must have been considerable.
Following the main experiment, in which the instrumented dummy had been equipped with the Avagear rescue vest, it was subjected to a second avalanche on a close by west-facing slope, this time for reference purposes not wearing any rescue aids. This avalanche had a release height of 40 cm, a width of 50 m and a length of approximately 250 m. It resulted in the dummy being completely buried in a seated position, so that only a small part of the dummy's hood was visible on the surface.

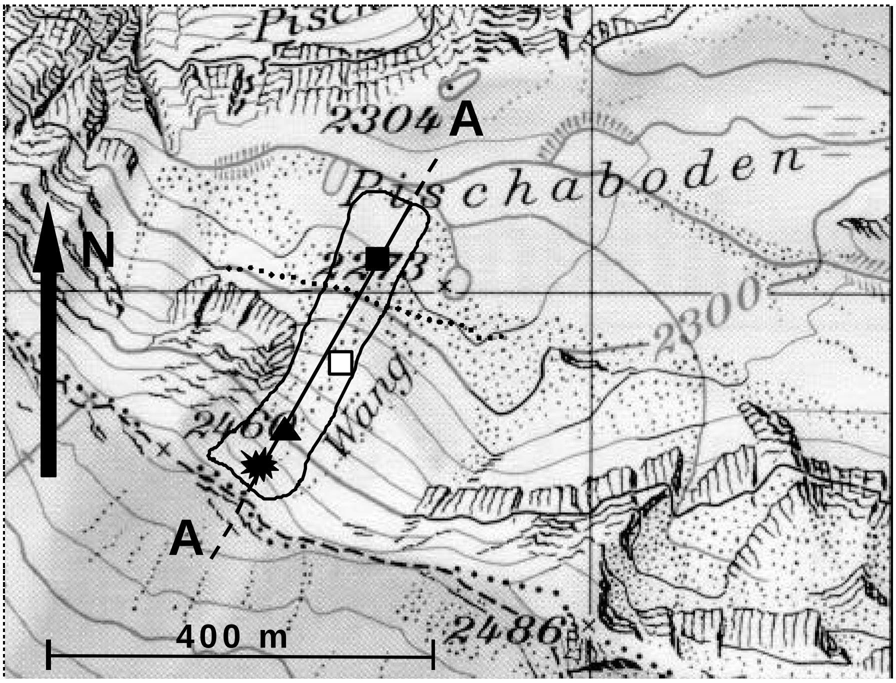

Fig. 4: Experimental slope "Wäng" in the ski region Pischa with the positions of the explosive charges (*), initiation-(triangle) and the end positions (Squares) of the dummies. Reproduced with the permission of the Eidg. Landestopographie.

Table 1 Labels, equipment and test results of the employed dummies (gv: totally buried, gv (s): totaly buried with visible parts, tv: partly buried, nv: not buried.

label	Dummy-type	Rescue device	Type of burial	Burial depth in cm
1	CMC	ABS duales System	gv (s)	50
2	CMC	K2 avalanche ball	gv	80
3	CMC	ABS Monoairbag	gv (s)	50
4	CMC	K2 avalanche ball	gv	25
5	CMC	avagear Rettungsweste	tv	0
6	CMC	ABS Doppelairbag	gv (s)	60
7	CMC	avagear Rettungsweste	tv	0
8	CMC	keines	gv	50
9	CMC	keines	gv	30
10	CMC	keines	tv	20
11	CMC	keines	gv	150
12	CMC	ABS Doppelairbag	nv	0
13	Hybrid-III	avagear Rettungsweste	tv	0

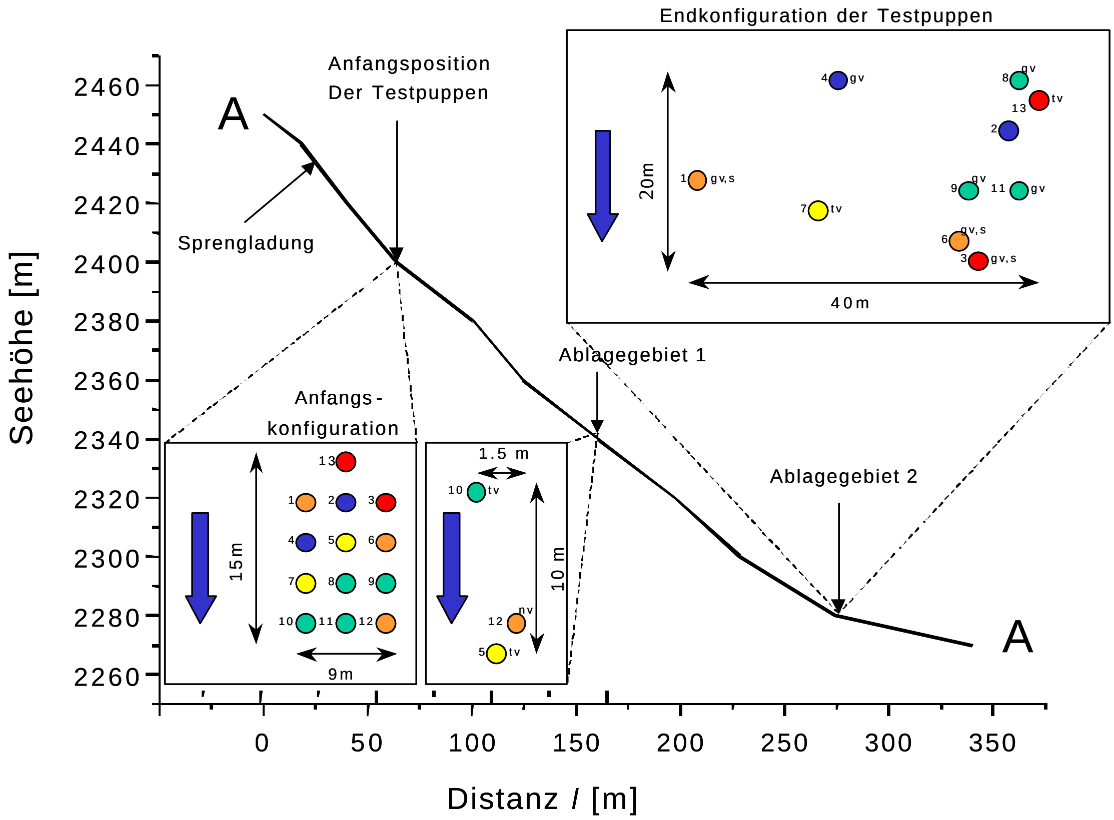

Fig. 5: Profile along line A-A (Abb. 4) mit with Start- and final positions of the test dummies. Labeling of the dummies as given in Table 1.

Abb. 6: Test slope after avalanche release (see Fig. 5).

5 Results

5.1 Burial depth and location of the dummies with and without avalanche airbags

The burial depth is a major factor in the likelihood of survival for the buried person (TSCHIRKY et al. 2000). The details of burial depth and severity are given in Table 1. Comparing burial depths (measured from the face of the dummy to the surface of the snow) as illustrated in Fig. 7, it is striking to see that the burial depths of the dummies without airbags is significantly higher than those of the dummies with airbags, although the difference cannot be considered statistically significant. The burial depths of the dummies with (different kinds of) airbags are of the same order of magnitude.

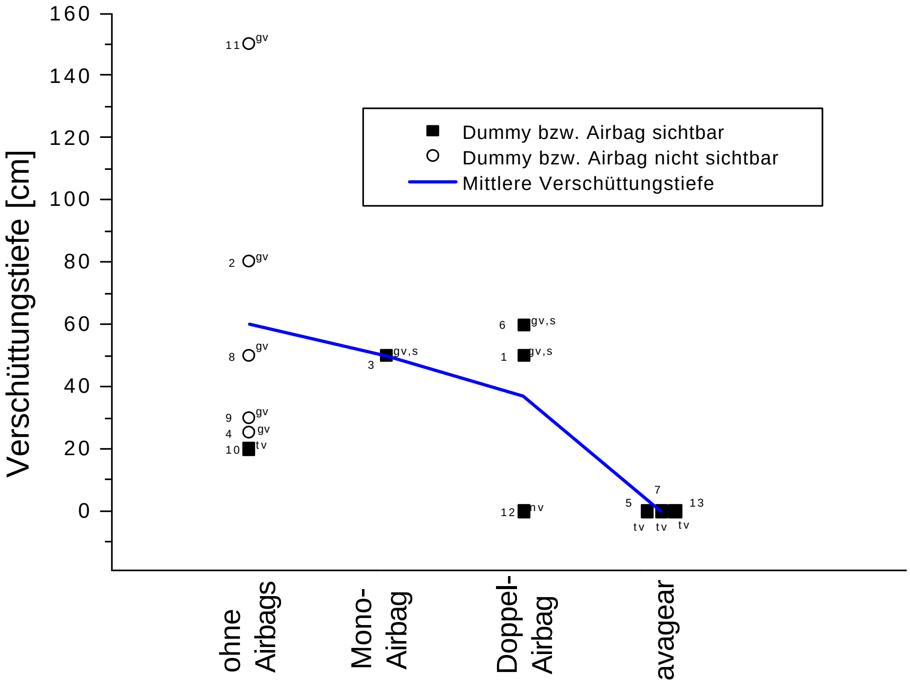

Fig.7: Burial depth of dummies depending on used rescue device

The fact that the faces of the dummies with the Avagear rescue vest were always found in the proximity of the surface appears to verify the hypothesis that the Avagear airbag, which is positioned close to the head, does indeed aid the lifting effect on the head and upper body. In fact two of the three Avagear-wearing dummies were found in an upright or seated position in the snow, whereas the dummies with the mono or dual airbag were found either face-up or facedown in a horizontal position. This result could explain the larger burial depths of the dummies equipped conventional airbags compared to the burial depths of the Avagear equipped dummies. Should further experiments confirm that this is the case, then the head near positioning of the airbag could be rated as a real improvement on the conventional airbag. However in view of the low number of Avagear rescue vests tested, this statement remains a cautious one. Moreover it is important to remember that the use of the Avagear device can seriously restrict sight and mobility, so that the possibility of evading the avalanche is substantially reduced if not entirely removed. The ABS airbags were visible at the surface of the deposit in all cases except the defect one.

5.2 Functionality of the K2 "Avalanche Ball"

Two dummies were equipped with the K2 "Avalanche Ball". These dummies had the same burial criteria applied to them as the ones without airbag. They were found lying on their back at depths of 25 and 80 cm respectively. Both avalanche balls were visible on the surface of the snow deposit. The location of the dummies was greatly facilitated by the ball and attached cord, so that the dummies could be located and dug out within 10 and 12 minutes respectively. Here, the location time was defined as the period of time it took a helper to reach the dummy from the point of release of the avalanche and complete free its face from snow. The distance between the ball and the dummy was 6 m in each case in keeping with the total length of the cord. Principally speaking the K2 avalanche ball cannot contribute to reducing the burial depth, does however facilitate the visual location of an avalanche victim. On the other hand it is important to remember that the K2 avalanche ball has to actively triggered by the wearer himself and that it is impossible to exclude the possibility of the ball itself being buried underneath the snow, thus effectively rendering rapid location and rescue impossible.

5.3 Loading of the cervical vertebrae

The variation with time of the transverse force components and turning moments acting in the cervical vertebrae region were recorded by the instrumented dummy wearing the Avagear rescue vest in the main experiment and can be seen in Figs. 8 and 9. The x-axis is defined as the line of sight of the dummy, the y- axis horizontal towards the right shoulder and the z-axis as pointing upwards along the cervical vertebrae.

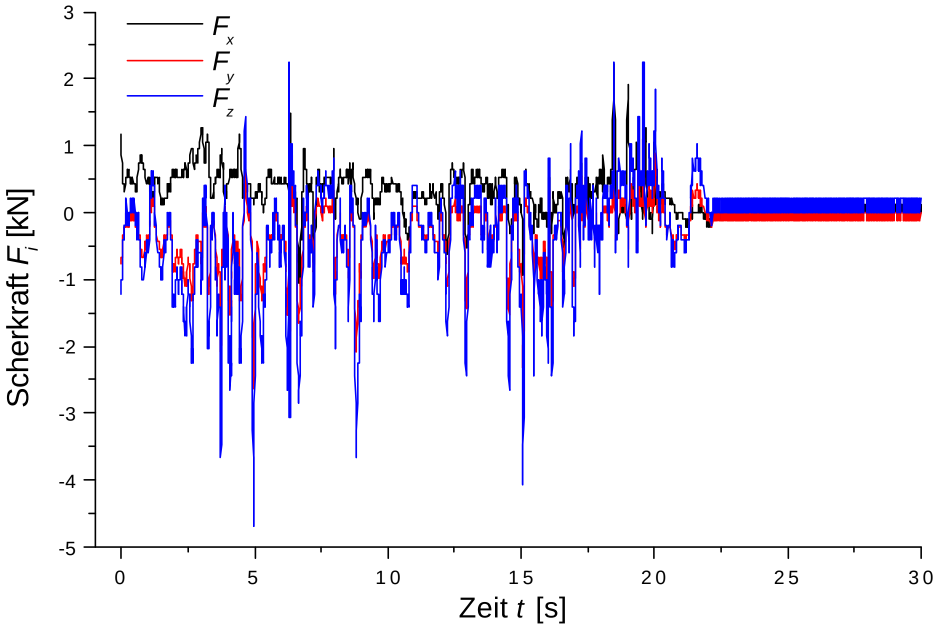

Fig. 8: Variation of the shear forces acting on the cervical vertebrae of the instrumented dummy wearing an Avagear rescue vest with time.

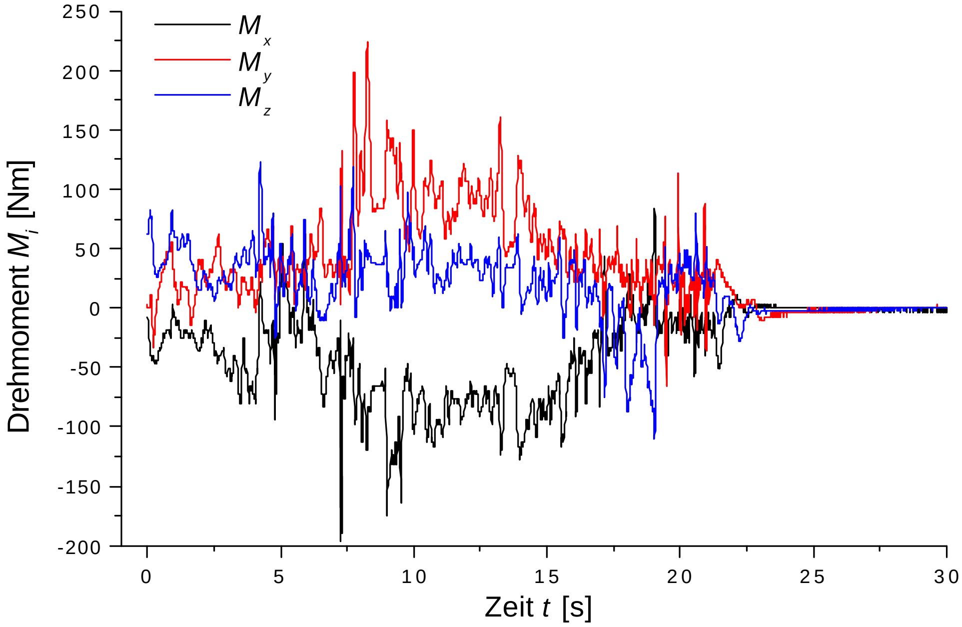

Fig. 8: Variation of the turning moments acting on the cervical vertebrae of the instrumented dummy wearing an Avagear rescue vest with time.

The maximum values for the forces and turning moments acting on the instrumented dummy with the Avagear rescue vest were 4.5 kN and 200 Nm respectively. The reference experiment, which involved the instrumented dummy being subjected to a slightly smaller avalanche without any rescue equipment, produced values of 14 kN and 300 Nm respectively for the maximum force and turning moment. Considering that the avalanche in the reference experiment was smaller than the one released for the major experiment, this might be an indication that the Avagear rescue vest is capable of reducing the forces experienced by an avalanche victim in the area of the cervical vertebrae. Although a good indicator, this statement also is of little statistical importance.

Principally it is very difficult to deduce the potential for injury from the measured loads and turning moments. It is however possible to say that the loads and turning moments that were recorded –given unfavourable circumstances – could cause serious or even fatal injury to the cervical vertebrae.

The current measurements of the loads acting on avalanche victims give the impetus to reconsider the way mechanical injuries due to avalanches are interpreted and how their causes are determined: It is to be clarified whether or to what degree avalanche airbags reduce (or possibly increase) the effects of the avalanche on the victim. It might be possible to reduce the number of avalanche related fatalities if suitable safety measures such as the Avagear were to be used more widely. Record of avalanches involving human victims show that most fatalities due to mechanical injuries were not or only partially buried (TSHIRKY et al. 2000). Answers to these complex questions will require further measurements with an instrumented dummy in an avalanche and the intensive co-operation between avalanche experts, bio mechanics experts and specialists for accident injuries.

7 Conclusions

In February and March 2001 the Swiss Federal Institute for Snow and Avalanche Research (SLF) conducted tests on dummies with and without avalanche airbags in the Davos region of Switzerland. Two preliminary experiments were undertaken with an instrumented dummy to obtain reference measurements for victims not wearing an airbag. In the main experiment a total of 13 dummies (6 without and 7 with airbags) were positioned on the slope, an avalanche initiated and the effect of the airbags on the burial and flow characteristics investigated.

In summary the most important observations are as follows:

- All airbags were visible after the avalanche had come to a stop thus permitting rapid location of the dummies.
- All but one dummies without airbags were buried completely and all except one had to be located with the help of other devices (electronic emitter and avalanche ball).
- In the context of the experiment, wearing an airbag reduced the burial depth of the heads and the faces of the dummies.
- The K2 "Avalanche Ball" does not reduce the depth of burial. In the tests it facilitated rapid visual location of the dummies.
- Dummies equipped with the mono or dual airbag tended to come to rest face up or face down in a horizontal position. In most cases the airways were covered in snow.
- The use of Avagear Airbags, which are positioned around the head in the inflated state, resulted in the partial burial of the dummies in all three cases. The heads and therefore the airways were above the snow surface when the avalanche came to a stop.
- The loads that were measured in the region of the cervical vertebrae are of such a magnitude that can lead to fatal injuries. There are indications that the loads on that area can be reduced by the Avagear rescue vest, but that the loads experienced by the dummy are still of dangerous magnitude.

These observations lead to the following conclusions:

- The avalanche airbag can reduce the severity of the effects resulting form avalanche burial by reducing burial depth and facilitation of rapid localisation. It cannot in principle prevent burial, but represents a useful addition to conventional avalanche safety equipment (electronic emitter, spade, avalanche probe).
- The effectiveness of the dual airbag system is comparable to that of the mono airbag system.
- In the context of this investigation, the orientation of the dummies (seated position / upright or horizontal) appears to have been dependent on the type of the airbag used. A generally applicable statement on this finding cannot be given due to the low number of data points obtained.

- Based on the results obtained the K2-"Avalanche Ball" does not represent a significant advancement in the area of avalanche safety equipment.
- The loads on the cervical vertebrae region of a person caught in an avalanche, which were measured with the help of a instrumented crash test dummy, are considerable and should be investigated further as a matter of urgency. I particular this further work should look at the effect different airbag types have on the applied loads and turning moments.

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